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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

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The Geoff Brown Memorial Lecture, AGM November 1999
Inaccessible Earths?

Dr Dave Rothery

Geoff Brown was head of the Earth Science Department when he was killed by an eruption on Geleras Volcano in 1993 and we have been saddened by the recent loss of Peter Francis. This talk contains material that I hope would have interested both Geoff and Peter.

Geoff wrote a book called *The Inaccessible Earth* with Alan Mussett from Liverpool, published in two editions. Geoff and I never collaborated on any research although I am sure we would have done so had he lived, but I did suggest some things that could be included in the second edition of *The Inaccessible Earth*. The first 100 or so pages cover the formation of the solar system and other planetary bodies and it is on that part of the book that I want to concentrate. It includes material that should be familiar if you have done S267 *How the Earth Works* or S281 *Astronomy and Planetary Science*.

I want to explore what we have learnt since the second edition of *The Inaccessible Earth*. The bodies I want to talk about are Earth-like which means that I do not want to deal with the giant planets. I may talk about their satellites, but not the giant planets themselves. As a geologist I am fascinated by solid planets such as Mars and the large satellites within the solar system.

Between the publication of the first and second editions more information about Venus became available. Radar-imaging by the Magellan space probe unveiled Venus by seeing through its dense atmosphere and imaging the surface. In addition, radar altimeters allowed global topographic mapping of Venus and revealed a surface very unlike that of the Earth; it may look to have continents and oceans but there is no sharp distinction between oceanic and continental crust, no obvious spreading axes and no subduction zones – it does not behave like the Earth at all! Although it is about the same size, mass and density as the Earth, it is a very queer planet. That is the fascination about planetary science - doing comparative planetology. So what have we learned about other planetary bodies since the 2nd edition of *The Inaccessible Earth*?

One theme of Geoff's book concerns the interiors as well as the surfaces and there have been some considerable advances about the interiors of several planetary bodies. In July 1996 with the landing of Mars Pathfinder we saw the Sojourner Rover driving across the rock-strewn surface of Mars, approaching close to rocks and sending us close-up pictures of boulders (Figure 1). The textures were revealed and some attempts were made to analyse the rocks themselves. Unfortunately, it is still not clear whether they are andesites or basalts covered in a silica-rich dust. There were rocks with different surface textures which we could examine in stereo; you can download stereo pictures from the Web and look at them.

It was not just the pictures and the analysis from Pathfinder that revealed information about Mars. Instruments were placed on the surface which send signals back to Earth as Mars rotates, giving details of the fluctuating distance between Earth and Mars which enabled us to work out the location of the pole of rotation of Mars. This was first measured in 1973 by the Viking Landers and since then the pole of rotation of Mars has wobbled slightly. As the rate of change of Mars' spin axis is controlled largely by the size of Mars' solid core this tells us about the size of the core, which we can now tell must be between 1300 and 2000km in radius. That is the most accurate data available and will be until we land on Mars with seismometers that can detect seismic waves that have travelled from the core-mantle boundary. Lidar (laser reflection from Mars' surface) from the Mars Global Surveyor currently in orbit about Mars enables us to construct global hemispheric views of Mars' topography with great vertical precision. Mars Global Surveyor also carries a camera, which is giving images of the best resolution of 2.5m pixel size. Figure 2 shows one such image covering a possible landing site for Beagle 2, the British- (and OU-) led lander due for launch in May/June 2003 and landing at the end of December of the same year. The trouble is the landing area on Mars cannot be targeted with great precision, the target ellipse is 200km long and 60km wide, so a large

Figure 1. A view from the Sojourner Rover, showing the Mars Pathfinder lander in the background.

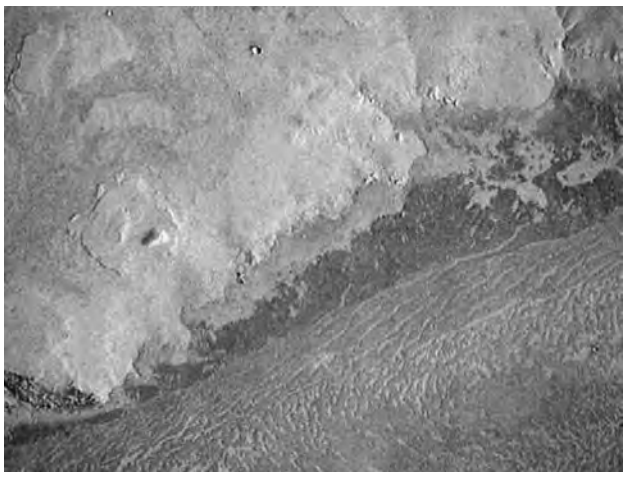

Figure 2. Mars Global Surveyor image covering an area only a few km across. The dark terrain in the lower part of the image is a basalt lava flow with texture very similar to what you would see on an aerial photograph of lava flows in Hawaii. The other half of the image is smoother, and appears to be an eroded sedimentary terrain.

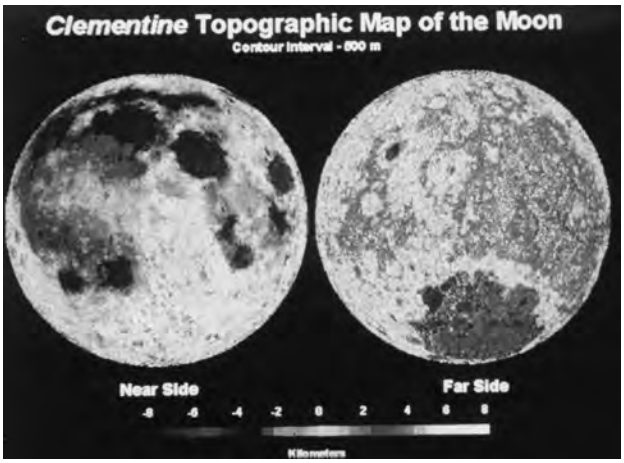

Figure 3. Lunar global topography as mapped by Clementine.

area is needed in which it is safe to land. It is going to be quite difficult finding somewhere suitable to land as we are not going to get high resolution pictures covering the whole surface as each picture only covers a strip a few km wide.

Perhaps you heard about ice being discovered near the Moon's poles. It has come about via an indirect method of looking at the slowing down of cosmic neutrons being affected by the ice. Clementine orbited the Moon in 1996 to reveal its global topography (Figure 3). Lidar showed that on the familiar nearside of the Moon the low-lying dark correspond to the mare basins such as the Sea of Tranquillity where Apollo 11 landed. An enormous hole, the South Pole-Aitken Basin, occurs near the south pole on the far side of the Moon which was not recognised until Clementine beamed back images. The South Pole-Aitken Basin had not been recognised as it is light coloured like the lunar highlands; it is a big impact structure that has escaped flooding by dark lunar basalts. The data can be used to construct a model of crustal thickness where the crust can be seen to be thinner in the basins. We also have gravity data. There is more pull over an increasing mass (a mascon) so the orbiting spacecraft will speed up a little; conversely, if there is a decreasing mass it will slow down, so gravity can be mapped from satellites in lunar orbit and presented as a free air gravity anomaly map. The gravity is high over the mascons because the crust is thin; the mantle is raised underneath due to isostasy and basalts have flooded into the basins. There is mantle near the surface and dense basalt at the surface, creating a mass excess which shows up on the free air gravity. The South Pole-Aitken Basin has not been flooded by basalts so does not show up as a lunar mascon.

Galileo went into Jupiter orbit about December 1995 and its mission is due to come to an end in a few weeks time (unless we are very lucky). It has been making repeated passes close to Jupiter's four largest satellites and we now know much more about their interiors and their surfaces. Due to new revelations regarding Jupiter's satellites, I have produced a second edition of my Oxford University Press book *Satellites of the Outer Planets* which will be available in the UK in January 2000.

The four large satellites of Jupiter are called the Galilean satellites as they were discovered in 1604 by Galileo who saw just four tiny points of light orbiting Jupiter with one of the first telescopes, so the mission was named after him (Figure 4). The outermost satellite is Callisto, then Ganymede, Europa and Io. Io, the closest to Jupiter, is just a tiny bit bigger than the Earth's Moon; the biggest, Ganymede, is a bit bigger than the planet Mercury. They are worlds in their own right because if they did not orbit Jupiter they would be regarded as planets. They are Earth-like in many ways, especially those close to Jupiter where tidal heating has kept them active. Small bodies not receiving tidal energy would have run out of internal heat a long time ago, their surfaces would be dead and the only processes disturbing the surface for the past three billion years would be impact cratering similar to that on Earth's Moon.

Their internal structures have been revealed by Galileo. The densities of Callisto and Ganymede are roughly the same, about 1.6 x 10^3kg/m^3. This is about one and a half times the density of water so they cannot be made of ice and it is not dense enough to be made of rock (3.5 x 10^3kg/m^3); similarly they cannot be made of iron (6-7 x 10^3kg/m^3). We know that the surface of Callisto, Ganymede and Europa are icy because of the way they reflect sunlight, but they cannot be ice throughout as they are too dense. The Galileo gravity and magnetic data have revealed that Callisto is not a differentiated body; there is ice near the surface but there is no core/mantle distinction inside, at best it is a very weakly differentiated rock/ice mixture. It appears that there was never enough heat to allow the ice to be mobile, let alone melt, so any rocks could not segregate towards the centre; therefore, it has no core.

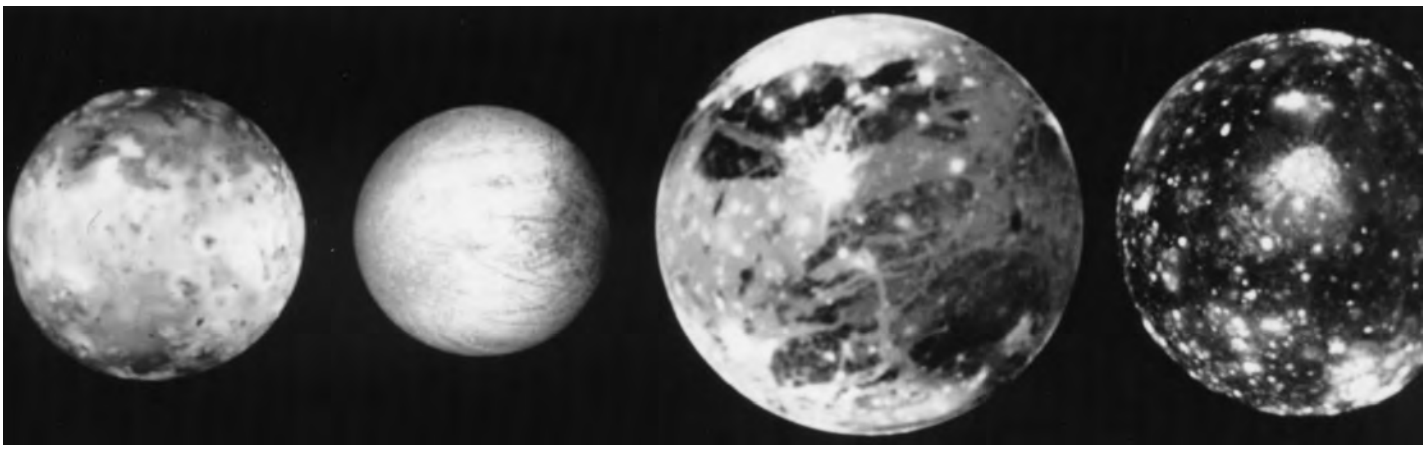

Figure 4. Global views of Jupiter's four largest satellites. From left to right: Io, Europa, Ganymede and Callisto, shown at the correct relative sizes. Ganymede, the largest satellite in the solar system, has a radius of 2631km.

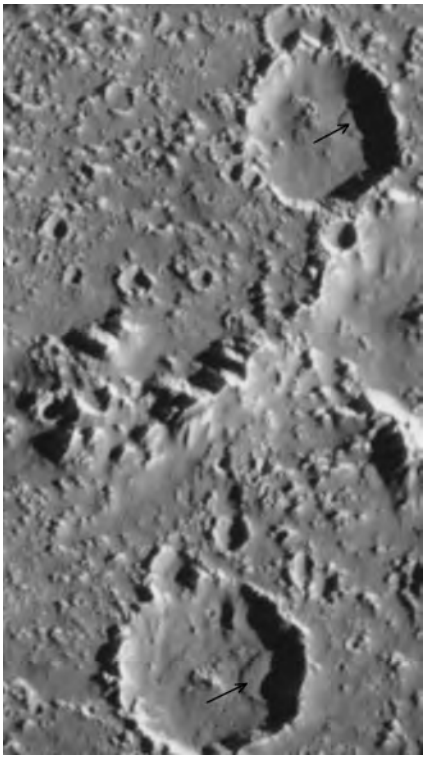

Figure 5. Galileo image of part of Callisto. The two largest (10km diameter) craters each have a debris avalanche deposit on its floor (arrowed) that has been caused by a landslide from its eastern wall.

This sort of discovery is big science. The cover of Nature Vol. 384 No.6609, 12 December 1996 captioned *Galileo at Ganymede*, shows a cut-away model of Ganymede constructed thanks to Galileo gravity and magnetic data which constrained the internal structure. If a body like Ganymede moves into a zone in which it receives enough energy to allow heating, the ice interior becomes mobile and dense material segregates towards the centre. Previously it was known that Ganymede had an icy outer layer and a rocky outer core, but Galileo revealed that there is an inner iron core. Ganymede has a magnetic field, but it is not clear whether the field is generated within the iron core or the icy zone. It has been suggested that there is a conductive brine which convects to generate a magnetic field. This is not plausible to geologists because the surface is old and heavily cratered with no fresh eruptions on the surface, so there is no surface evidence of a vigorously convecting briny ocean needed to generate a magnetic field. We think that the magnetic field is generated in the iron core and not in the ice.

Europa has a core composed of 95% iron and 5% of other elements. The big iron core is much bigger than that of the Moon; it has a rocky mantle or outer core, with a young icy surface. It is almost certain that there is liquid water a few kilometres below the solid ice which makes Europa a superb place to want to go and visit. One of the good things about planetary exploration these days is that in a way we can all participate in such visits - there are images on the Web from robots in orbit and on planetary surfaces, and by consulting these you are in the same position as the scientists controlling the mission, seeing these new worlds through the eyes of our robotic surrogates.

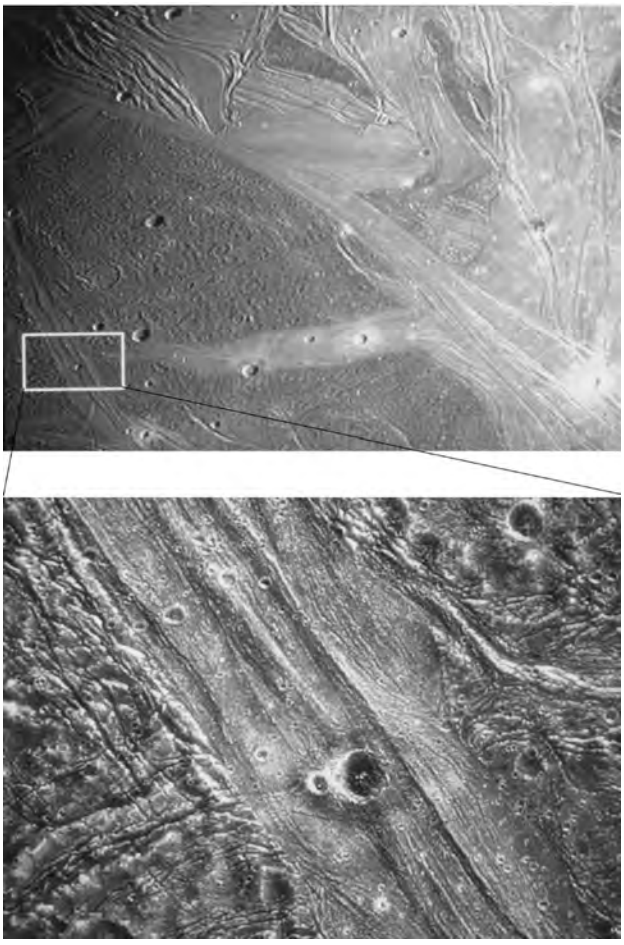

Figure 6. Top: 660 km wide region of Ganymede, showing pale and dark terrain. Bottom: the boxed region from the upper image, seen at greater resolution, when the sun was higher in the sky. Complex fractures are revealed even in the dark terrain.

Io, the innermost satellite, has a large iron core, bigger than that of our Moon, and a rocky mantle. There is no ice on the surface of Io but there are many active volcanoes.

Galileo has sent back some superb close-up images of the surfaces of the satellites. The surface of Callisto could be mistaken for the lunar highlands - a heavily cratered, ancient surface, with no new surface features such as faults, just lots of old craters. Surface temperatures in the Jupiter system are -140°C so ice is the consistency of rock and can sustain impact cratering. When examined closely there are some smooth areas and there is a dearth of small impact craters; Callisto is lacking in craters less than a few 100m in diameter. Some 30km diameter craters have debris avalanche deposits on their floors produced by landslips sliding off the crater; so there is instability of slopes on Callisto (Figure 5). Although most of Callisto's surface is quite dark there are plenty of light areas, not just where the sunlight is catching a slope, but on the high ground which appears more reflective than the low ground. There, the albedo is about 20% (pure ice is 90%) which is quite dark, so the surface may be made of sooty, carbon-rich material and organic molecules which are disseminated into the ice. This ice is being hit all the time by meteorites and micrometeorites and being broken up into fragments by the same processes that formed the lunar soil (or 'regolith'). When mete-

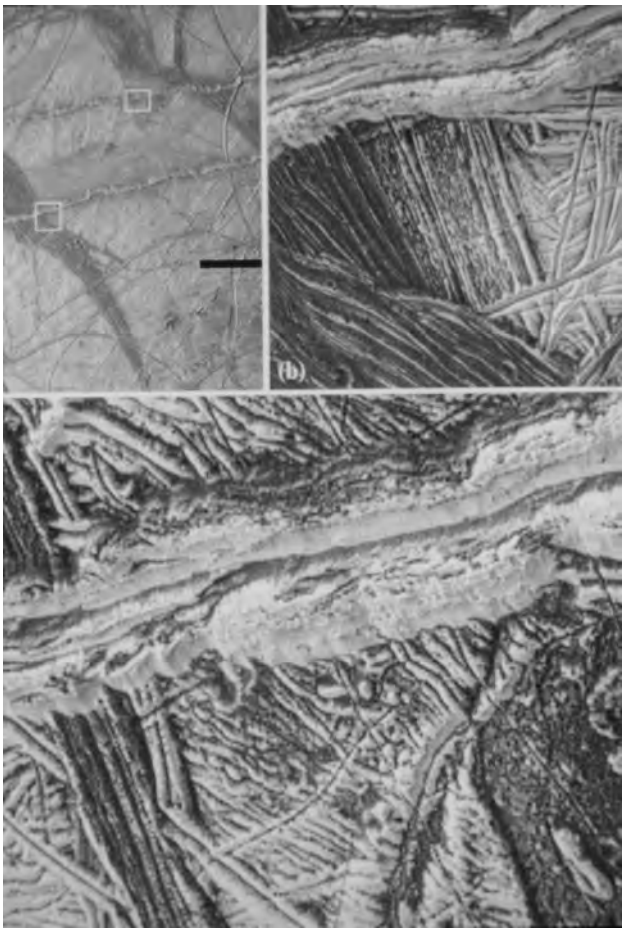

Figure 7. Top left: 150km wide region of Europa, seen at a resolution of 420m per pixel. The two boxed regions are shown at 26m per pixel at top right and bottom. It can be seen that the ridged and grooved surfaces get paler with age. These surfaces may have grown by incremental spreading. However, the youngest features of all are the two pale bands that cross the boxed regions. Here the icy surface crust may have ruptured to allow the water underneath to spurt up like the fissure eruptions on Hawaii. These fissures are very long and can be traced for hundreds of kilometres. At lower resolution (as seen in 1979 by the Voyager spacecraft) these features appear as a white strip with a thin black stripe along the centre, and so have become known as 'triple bands'.

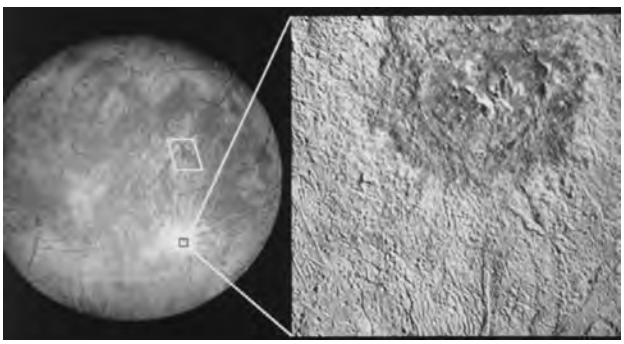

Figure 8. The crater Pwyll (26km diameter) on Europa. This does not have classic crater topography, because it was formed by an impact into thin ice (possibly about 5km thick). The white boxed area 1000km north of Pwyll is shown in Figure 9.

orites impact they vaporise the ice rather than the rock and sooty fragments. Some of the vapour molecules will be lost to space, but some will return to the surface and refreeze where it is coldest. This is on the top of the hills as they are more fully exposed to space. Removal of the ice leaves a darker rocky, tarry surface in the low areas. So although it is a dead world in terms of major movement of material there is still movement of both vapour and solid material. The dearth of small craters is perhaps explicable by their being eroded during the process which turns ice to vapour.

A global image of Ganymede shows it is quite patchy, with dark areas, pale terrains and the youngest craters brighter still. It seems that when a crater is formed on an icy body a lot of finely ground, powdery ice is ejected which is much brighter than the old ice. There are two different terrain types on Ganymede: a dark terrain and a pale terrain. Both are heavily cratered and hence must be very old (like Callisto), but the older craters are not so prominent and appear to have subsided whereas the younger craters are pristine in shape. The older terrain is cut by pale, younger terrain, but there are areas where there are multiple events and a strip of younger terrain is crossed by a similar strip in another direction. It is not known how this is emplaced, but clearly the old lithosphere has fractured to allow new material to well up and freeze, giving a new icy surface with a different texture. But whether the blocks are just moving apart or whether there is fracturing allowing flooding at the surface is not entirely apparent. There is a very complex history which generated Ganymede's crust and the closer you get the more complex it becomes (Figure 6). The pale terrain is covered with complex ridges and grooves. Normally the belts of pale terrain are quite broad, sometimes they are quite narrow and sometimes they are the same colour as old terrain. There is also evidence of tectonics on Ganymede; one old crater has been split and moved apart by about 20km, half its diameter. We very rarely see this kind of fascinating movement.

A map of Europa shows that it is the opposite of Ganymede; whereas on Ganymede the dark areas were older than pale areas, on Europa its oldest areas are pale and cut by belts of younger dark terrain. Europa is just a bit bigger than the Earth's Moon; it has a very young surface, there are very few impact craters, it is a much younger surface than Ganymede. It has been active in the geologically recent past, certainly within the past 100Ma, and I think it is active today. It is close to Jupiter so receives more tidal heating. Galileo has given us wonderful close-ups. The wedge-shaped dark grooves were previously explained as slabs rotating relative to each other with material filling the gaps. The new images show symmetrical patterning of light and dark stripes like a magnetic anomaly pattern at a mid ocean ridge. Under higher magnification it can be seen that one system of ridges and grooves is truncated by another system of ridges and grooves and all the surfaces, both young and old, are ridged and grooved (Figure 7). Cross-cutting relationships show that usually the younger areas are darker than the older areas. As you look closer the distinction between the two terrains breaks down.

Pwyll impact crater on Europa was formed where the lithosphere was relatively thin and has punctured the crust so there is no proper crater formed, but the ejecta from the crater can be clearly seen (Figure 8). Figure 9 shows a region 1000km north of Pwyll, where there are clear signs of a long and complex series of surface-forming events. Close-ups of the pale terrain with cross-cut-

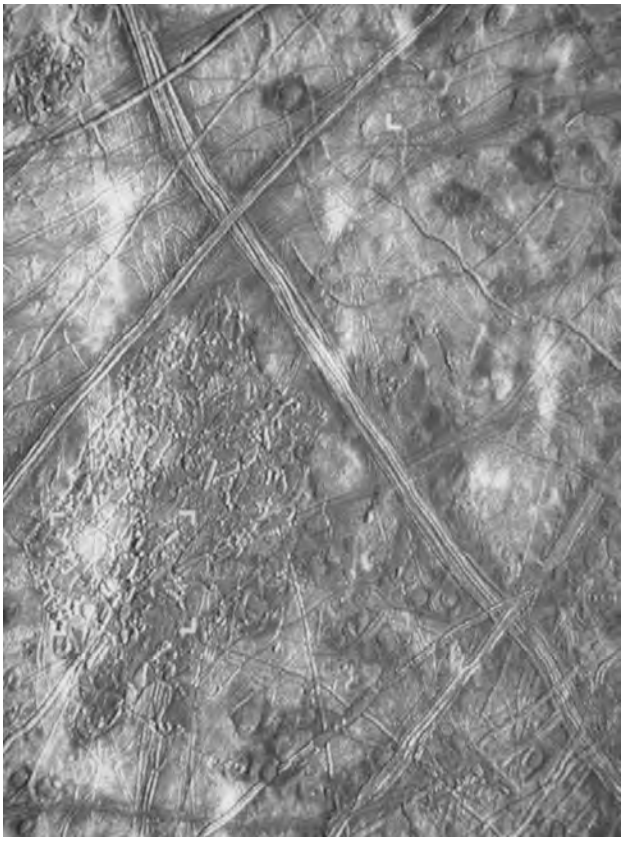

Figure 9. Galileo view of a 200km wide region of Europa (see Figure 8 for location). The darker material preferentially distributed either side of the triple bands is probably some kind of salt (but not NaCl) as the way the sunlight is reflected is consistent with water of crystallization held within some molecule like magnesium sulphate, although there are other things it could be. Between the lower branches of the 'X' shape formed by two cross-cutting triple bands is a region known as Conamara Chaos, where the ridged and grooved surface has been broken apart. Detail from this is shown in Figure 10.

ting ridges and grooves look like a ball of string punctuated with domes, which are where diapirs have forced their way towards the surface, some not quite reaching the surface, some breaking the surface and some spilling out over the surface. Sometimes the ball-of-string surface is completely broken apart by melting, surviving only as fragments that fit like a jigsaw with the pieces displaced (Figure 10). It is a bit like floes of pack ice in the Antarctic ocean where the ice cracks apart and the sea refreezes in between.

There are two competing models for the outer part of Europa above its rocky outer core. Below the cold brittle surface ice there could be either warm convecting ice or a liquid ocean. Even if the ocean no longer exists, it was probably there in the geologically recent past - but what is it like today? We do not know. It is fascinating to contemplate the options because if rock is hot due to tidal heating then the water is going to be drawn down into the rock to re-emerge as hot water into the bottom of the ocean. There are going to be Black Smokers just like in the Earth's oceans which could support communities of organisms sustained by sulphur-oxidizing bacteria-like organisms. If ecosystems in the Earth's oceans can be supported by geochemical energy why could it not be similar on Europa? It is the lure of the possibility of finding life on Europa that is the target of a future mission,

Figure 10. A 40km wide area of Conamara Chaos on Europa, imaged at 54m per pixel. Note the ice rafts, bearing the ridged and grooved (ball of string) texture typical of much of Europa's surface, and how some of these rafts could be fitted back together by simple displacement. Between the rafts is a jumbled surface that may represent the frozen top of an ocean that was temporarily exposed to space when the older surface broke apart.

Europa Orbiter, the first to go into orbit around a planetary satellite, is scheduled to be launched in about 2004. It is hoped to find a thin enough place on the ice for a robot submarine from a later mission to go hunting.

Io is the most volcanically active body in the solar system. Until last month Galileo had not been close to Io as the local high radiation belt has to be visited only briefly as the electronics get fried! So Galileo stayed outside the orbit of Io for most of this mission and observed the volcanic changes going on from a distance. It

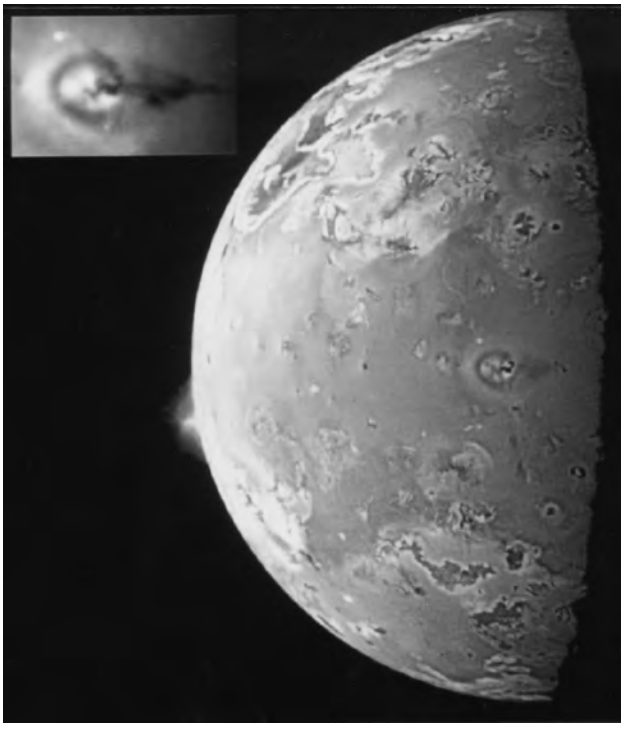

Figure 11. Galileo view of Io recorded in June 1997. An eruption plume from the volcano Pillan Patera is visible on the limb on the left hand side, and there is another one near the centre of the disk that is shown enlarged in the upper left.

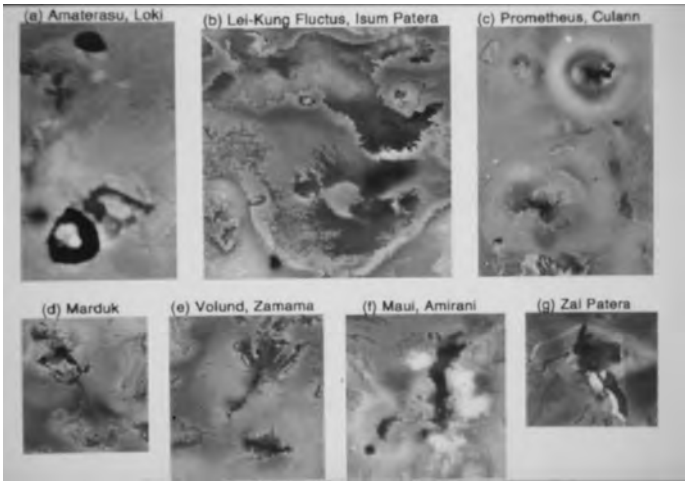

Figure 12. A gallery of some of Io's volcanoes, as seen by Galileo.

saw eruption plumes both on the limb and looking through them to the surface (Figure 11). These are powered by the explosive escape of sulphur dioxide, and reach about 150km above the surface. There is not a single impact crater on Io as the volcanic surface is very young; the average global rate of resurfacing is an average of about 1cm per year - a phenomenal rate of resurfacing. Io has a rocky core and a silicate mantle kept hot by tidal heating; it is not much bigger than the Moon and yet it has a dozen volcanoes erupting continuously. Volcanically exhaled gases contribute to the atmosphere. Infrared image shows hot spots corresponding to active volcanoes – it can be viewed telescopically from the Earth if you get above the water base in the atmosphere. Close-up pictures from Galileo show lava ponds, lava flows, eruption plumes – a wonderful volcanic surface (Figure 12). Those that have been seen while still active are understood to be silicate flows as the temperatures are too high for molten sulphur.

Galileo has made one suicide dive past Io, 100km above its surface, and is gearing up for another. If it survives there will be the opportunity to try to keep the mission going for a while longer. The highest resolution picture of Io recorded by the date of this talk forms part of Figure 13. This is the last Io picture that I had the opportunity to discuss with Peter Francis, and was recorded on 10 October 1999. At this high resolution we can see details of the surface as small as 10m across. This is clearly a volcanic surface with no impact craters, but the precise origins of the surface texture have yet to be worked out.

I'll finish with a flier for Cassini, a European mission which is due to go into orbit around Saturn in November 2004. It will send a lander named Huyghens to investigate the atmosphere of Titan, Saturn's biggest satellite, and will also land on the surface and give us some close-up views.

We have wonderful pictures from Galileo and there are a lot of exciting things taking place on Mars. It is a great pity that we do not have Geoff Brown to write a third edition of *The Inaccessible Earth*, because if he had wanted to keep looking at other bodies in parallel with the Earth, now is the best time to do it.

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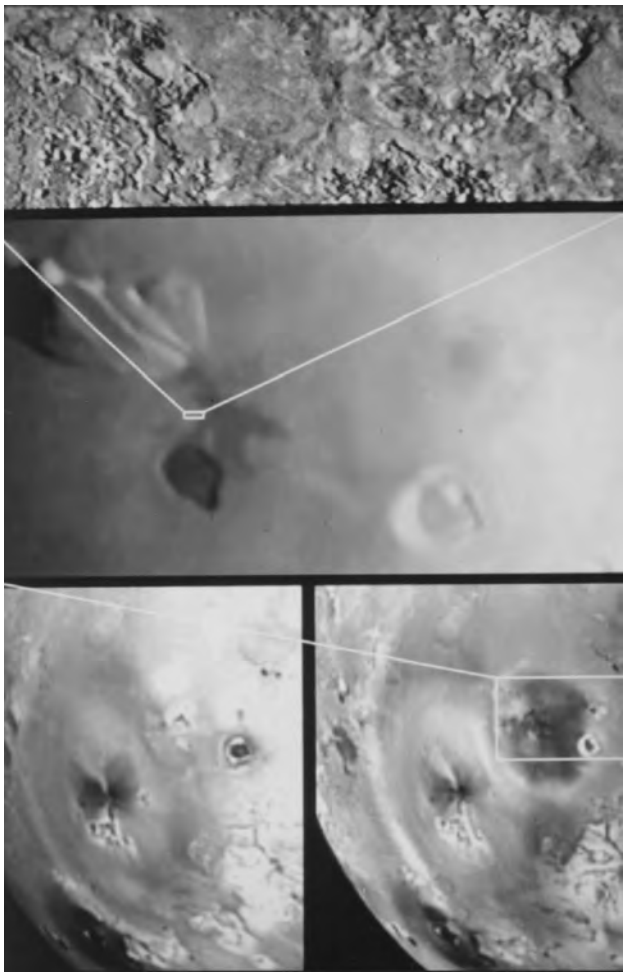

Figure 13. Below: Galileo view of a 1200km wide region of Io on 4 April 1997 (left) and 19 September 1997 (right). Between these two dates a short-lived high-temperature eruption plume occurred at Pillan Patera (see Figure 11) that distributed a 400km wide patch of dark material around the vent, which is the most obvious difference between the two images. The fainter 1000km diameter ring to the left marks the edge of the plume from a long-lived eruption of Pele volcano. Above: Successive close-up views of the area indicated, culminating with a 7.2km long strip of lava-covered terrain imaged by Galileo from a range of 617km during a close-flyby of Io on 10 October 1999.

The second edition was reviewed in OUGS Journal 15(2); copies of both editions are held in the Journal Editor's library and are available for borrowing.

Rothery D A, 2000, *Satellites of the Outer Planets* Second Edition, Oxford University Press, 242pp.

Author

Dave Rothery is a senior lecturer in the Open University Department of Earth Sciences and became Director of Teaching at the end of 1999. He is Course Team Chairman of S260 *Geology* and is also on the Course Teams of S267 *How the Earth Works* and S281 *Astronomy and Planetary Science*. As well as *Satellites of the Outer Planets* he has written *Teach Yourself Geology* (1997) and a further book for the 'Teach Yourself Series', *Teach Yourself Planets*, which is due to be published this summer.

An initial study of the Stanner - Hanter Complex in the Welsh Borderland: the oldest rocks in southern Britain

John Jaggard

Location

The Precambrian rocks of southern Britain are generally poorly exposed and in many instances are associated with major faults. The Stanner-Hanter Complex in the Welsh Borderland is no exception to this (Figure 1). It consists of three hogback hills, Hanter Hill, Worsell Wood and Stanner Rocks which trend 2.5 km along the southern end of the Church Stretton Fault, part of the more extensive Welsh Borderland Fault System (Figure 2). These hills show a series of exposures of dolerite, gabbro and minor granitic types. The fault-bounded nature of the complex means that the relationship with the surrounding Paleozoic and Uriconian sediments remains largely unproven.

Figure 1. General view Hanter - Worsell - Stanner looking northeast.

Little modern research has been undertaken on the Complex. The rocks have been variously described as a hypersthene trap (Murchison 1867); an Archean ridge (Calloway 1879); a Carboniferous laccolith (Raw 1904); a Tertiary igneous complex (Watts 1906); and a Carboniferous intrusion (Pocock & Whitehead 1935). Holgate & Knight-Hallowes (1941) suggested a Precambrian origin based on the occurrence of dolerite clasts associated with Longmyndian sediments in a nearby quarry. Much of the confusion must relate to the fault-bounded nature of the Complex which gives no direct stratigraphic control of its age of formation. In the late 1970s the general acceptance of the theory of plate tectonics resulted in a re-investigation of the Precambrian and Paleozoic igneous rocks of southern Britain. Thorpe *et al.* (1984) made the earliest developments by identifying the calc-alkaline nature of many of these exposures and interpreting this evidence as the product of Precambrian subduction.

The Stanner - Hanter Complex was not part of this study, perhaps because of its considerable alteration or possibly owing to the limited range of rock types. In 1980 the publication of a Rb/Sr isotopic age of 702 ± 4 Ma by Pachett *et al.* (1980) confirmed the Neoproterozoic age of the Complex whilst establishing it as the oldest dated rock sequence in southern Britain. More extensive dating of Avalonian rocks both in southern Britain and Maritime Canada has allowed Avalonian subduction to be refined into several stages.

Gibbons & Hõrak (1996) grouped the Stanner-Hanter Complex with the Malverns Complex placing both within Avalonian Event 1, the early arc-construction phase, which has been dated at 677Ma. Implicit in this interpretation, however, is the assumption that the Stanner-Hanter rocks have a calc-alkaline composition. Slightly older dolerites and gabbros in the Avalonian of Newfoundland have a more primitive oceanic affinity related to the rifting and formation of primitive oceanic crust.

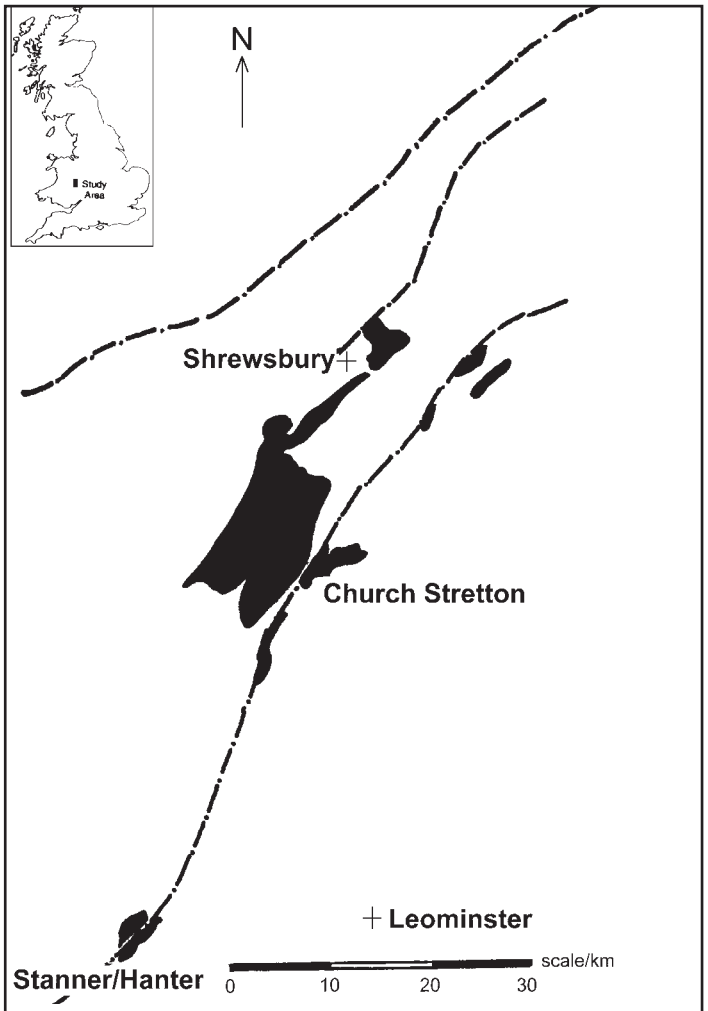

Figure 2. Precambrian exposures related to the Welsh Border Fault System. (After Gibbons & Hõrak 1996)

The tectonic setting

Avalonian magmatism appears to have continued for over 100 Ma with the early arc-construction event followed by two further distinct magmatic episodes at 620 - 600 Ma and 570 - 560 Ma. The extent of this arc is present in Wales and as far south as the Channel Islands where it includes the Jersey and Alderney Cadomian volcanics and a sequence of turbidite sediments (the Jersey 'shale', Harris 1992). The whole series of events relates to the subduction of oceanic crust in the Neoproterozoic along the western margin of Gondwanaland. Initial subduction during this early period was towards the east, at right angles to the continental crust, but with the passage of time this angle gradually became more oblique towards the southeast (Figure 3). This may have induced a change in the crustal stress regime which manifested itself as a series of NE/SW strike-slip faults. The angle of con-

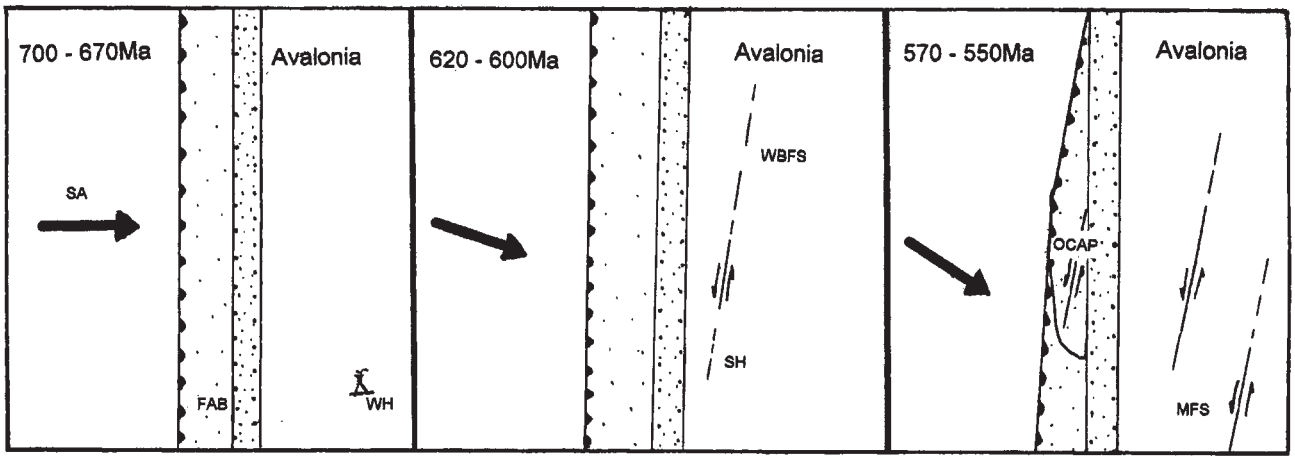

Figure 3. Evolution of the Avalonian subduction system 700 - 550Ma.
SA - subduction angle; FAB - Forearc basin; OCAP - Ocean crust accretionary prism; WH - Warren House Group
WBFS - Welsh Borderlands fault system; SH - Stanner - Hanter; MFS - Malverns fault system.

vergence continued to rotate towards the south until subduction stopped and the two plates moved past each other by transcurrent faulting. This dissected the subduction complex and juxtaposed the various components into what are now recognised as discrete terranes. The Coedana Complex in Anglesey and the Rosslare Complex in SE Ireland have been interpreted as an Avalonian terrane composed of a sliver of calc-alkaline intrusives and arc metamorphic rocks displaced from the main arc system by this transcurrent faulting (Gibbons &Hõrak 1996).

In nearby Strinds quarry there is an exposure of the Dolyhir Limestone which is generally accepted as being a reef facies of the Woolhope Limestone, although it contains some faunas similar to the Wenlock Shale (approx 425Ma) (Earp & Haines 1971). Below the limestone is a basal conglomerate which contains clasts of Longmyndian age as well as dolerite clasts which have been identified with those of the Stanner-Hanter Complex. The presence of Longmyndian clasts in the conglomerate has been taken as evidence that it is of Precambrian age and therefore that the Complex, which is the source of the dolerite, also dates from this period (Holgate & Knight-Hallowes 1941). However, since the Silurian rests unconformably on an eroded surface of the conglomerate and there is no record of deposition during the period from the late Precambrian to the Silurian in this location, the only real conclusion which can be drawn from this evidence is that the Complex predates the Wenlock.

Petrology/Geochemistry

The bulk of the Complex consists of dolerite which displays some localised differences in crystal size but which is consistent in its mineralogy. It comes into contact with the gabbro in a number of areas on all three sites. The contact area between the dolerites and gabbro has been closely studied both at the NE corner of Hanter and at the SW junction of Worsell Wood. In both cases the dolerite gradually becomes coarser over a distance of a few metres until it becomes at first a fine and eventually a coarse gabbro. On both sites there are small outcrops of porphyritic dolerite associated with this process. At the NE corner of Hanter there appears to be a direct contact between the two rock types but the dolerite in this case is a later dyke which is observed to cut through the gabbro. Where gabbro is present adjacent to the main granitic bodies, such as at the south end of Hanter Hill, then there is always a faulted contact. Fine granitic veins cut through the dolerite apparently at random. The sharp margins and small crystal size of these veins indicate quick cooling, and it may well be that these veins follow microfractures in the rock, indicating that the dolerite and gabbro were cold and had undergone some brittle deformation prior to the emplacement of the granite. The relative ages are unknown but evidence from xenoliths appears to confirm that the dolerite was solid and fractured by faulting before the granite intruded. No evidence of the country rock into which the intrusion was emplaced has been discovered.

Dark xenoliths, which occur both in the gabbro and granites, show well defined outlines and no evidence of heated or chilled margins (Figure 4). Thin section investigation shows them to be mineralogically identical to the main dolerite body. The sharp margins suggest that no assimilation of the xenoliths in the granite magma occurred, although given relative melting temperatures of granite and dolerite this would be unlikely. It is possible that they represent loose fragments formed as a result of brittle fault fractures in the dolerite prior to the granite intrusion.

The dolerite xenoliths which occur in the gabbro also have clean

Figure 4. Doleritic xenolith in granite (outlined) - Worsell Wood.

Figure 5. Possible layering in gabbro - Hanter Hill.

margins. They may represent fragments of basic magma which cooled and were later re-incorporated into the gabbro as a result of convection currents or flow in the magma chamber. In a small area on the top of Hanter Hill there is a single fault-bounded outcrop of microgabbro which shows fine striations some 2 - 3cm in width at an angle of around 30° (Figure 5). These features may represent layers which have been formed by cumulate processes within the magma chamber, but this feature is confined to just one area and shows no apparent mineralogical variation between layers. There is some evidence on the SE corner of Hanter Hill of blebs of gabbro within the main body which show compositional differences. These may be evidence of some form of magma circulation within a chamber.

Dolerite

The greater part of the Complex consists of fine dolerite but with localised variations which are mineralogically identical but display differences relating to variations in conditions during emplacement. Some of the dolerite samples examined show evidence of preferred mineral orientation at the microscopic level such as might be expected from a magma flow. These flow patterns are particularly evident where fine and coarse dolerite are in contact.

a) *Fine dolerite*

In thin section (Figure 6a) it is seen to be composed of euhedral microcrystalline plagioclase with a composition of 70% An (labradorite) granular clinopyroxene, probably augite, interpreted as primary magmatic minerals and subhedral chlorite and a green subhedral amphibole, probably actinolite, which formed during low grade metamorphism. Auxiliary phases are represented by an opaque mineral, possibly magnetite or ilmenite, which is present in high modal proportions. Epidote (sometimes as zoisite) and sphene also occur, probably as secondary minerals after ilmenite.

b) *Coarse dolerite/microgabbro*

Approaching the gabbro outcrop on the SE corner of Worsell Wood the fine dolerite evolves into gabbro, becoming gradually coarser over a distance of a few metres. In thin section the mineralogy remains the same, with euhedral plagioclase which shows signs of decay and subhedral clinopyroxene as the primary minerals. The poor condition of the feldspar makes it difficult to determine extinction angles but twinning, where visible, is broad, implying that this is a Ca-rich plagioclase. Secondaries are subhedral chlorite and green-brown subhedral amphibole. The brown amphibole occurs both as discrete crystals and as an intergrowth within, and rimming, the pyroxene - this is hornblende and it is part of the retrograde metamorphic texture. Again, there is a high proportion of magnetite/ilmenite and some epidote. Slower cooling occurred and larger crystals formed. There is some evidence of flow relationships within coarse and fine dolerite in this area, indicating that they were emplaced at the same time as part of the same intrusion.

c) *Porphyritic dolerite*

The third form of dolerite is porphyritic and again occurs in the contact zones between gabbro and the fine dolerite both on Hanter Hill and Worsell Wood. It contains xenocrysts of plagioclase which were probably derived from the gabbro and subjected to some secondary melting on mixing with the dolerite. Composition of these xenocrysts is richer in An than the groundmass, approximating to bytownite. The groundmass resembles the fine dolerite with labradorite and granular pyroxene as primary minerals and auxiliary ilmenite/magnetite with some secondary granular chlorite and epidote.

Xenoliths

Fine dolerite xenoliths are present in the granites of Worsell Wood and in the gabbros generally. The xenoliths within the granite are identical in composition to those of the main dolerite body. Those from the gabbro show identical feldspars but contain augite (Figure 6b). Secondary minerals show biotite rimmed by chlorite.

Gabbro

The gabbro throughout the Complex is generally highly altered which makes individual minerals difficult to identify. On the east side of Hanter Hill, however, a number of outcrops appear reasonably fresh and less altered. Where the primary mineralogy can be identified under a hand lens, plagioclase feldspar, a dark pyroxene and a dark fibrous amphibole, probably actinolite, can be discerned. Thin sections taken from those areas where the primary mineralogy can be seen reveals an identical mineralogy to the dolerites (Figure 6c). Euhedral plagioclase, with a composition of An 50-70% (labradorite), and subhedral augite locally show exsolution textures from the primary minerals. The secondaries consist of pale green euhedral amphibole, anhedral chlorite and epidote (Figure 6d). Ilmenite/magnetite are also present as auxiliary minerals. Crystal size is between 2 - 5mm and no preferred orientation is shown. At the SW end of Hanter Hill where the gabbro comes into contact with the granite there is evidence of retrograde metamorphism, shown by the presence of quartz and a dark green amphibole, actinolite. The presence of quartz together with actinolite, chlorite, epidote and albite is typical of the greenschist facies implying a moderate to high geothermal gradient during formation.

Granites

White to pink granite occurs either as veins within the dolerite and gabbro or as discrete large bodies within the Complex. The veins vary in width from less than 1cm to 0.75m in width and are completely random in orientation.

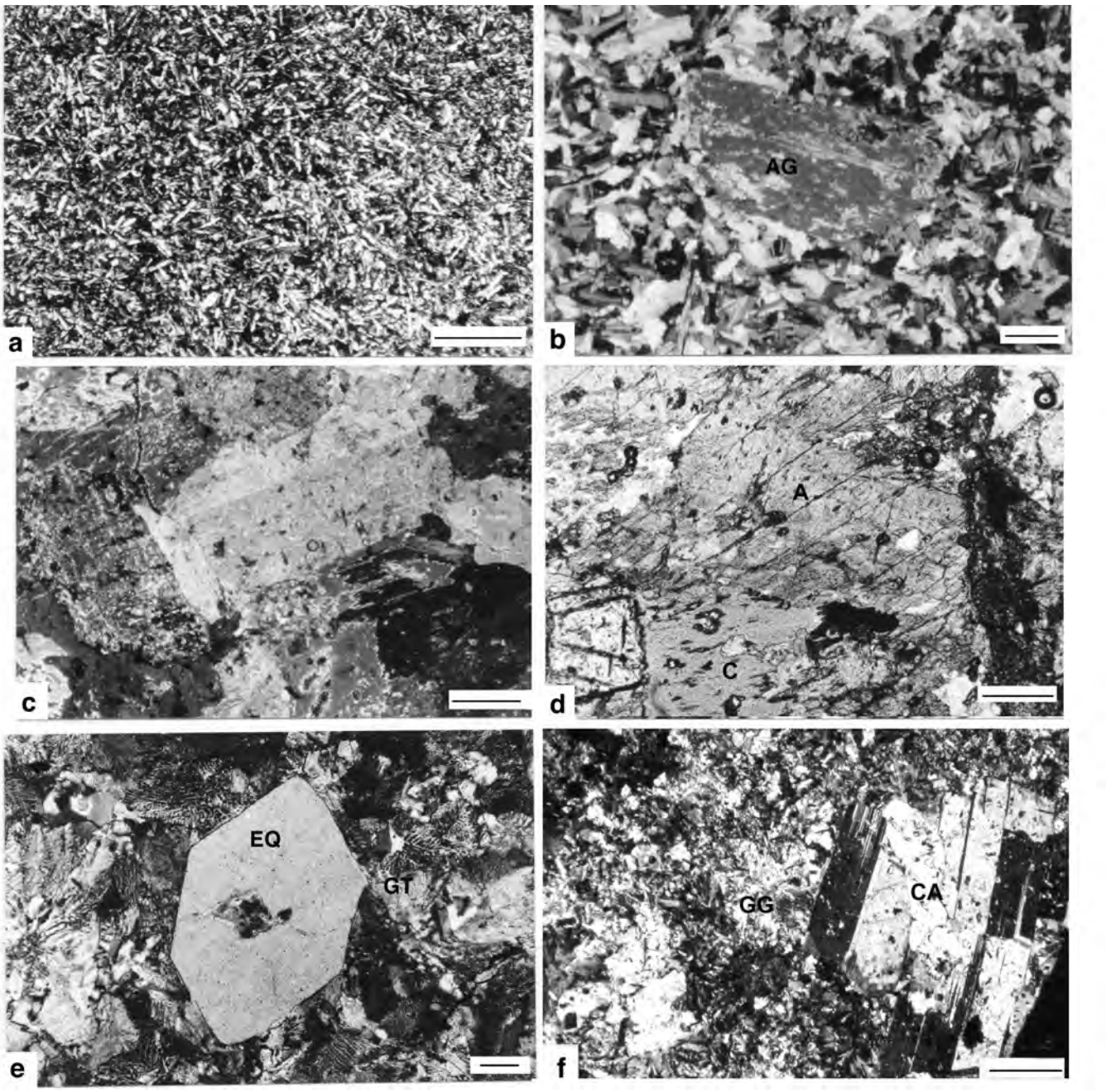

Figure 6. a) Hanter Hill dolerite, xpl; b) Dolerite xenolith in gabbro, xpl; c) Hanter Hill gabbro, xpl;. d) Hanter gabbro-greenschist assemblage, ppl; e) Hanter Hill granite showing granophyric texture; f) Worsell Wood granite, xpl. Scale bars 0.5mm.

A - actinolite; AG - augite; C - chlorite; CA - Ca-rich xenocryst; EQ - euhedral quartz; GG - granophyric groundmass;

Three main discrete granite bodies occur within the Complex. The first is at the SW end of the summit of Hanter Hill. It consists of a fault-bounded block of granite which displays small shattered areas of pale pink granite on the surface. The granite is fine grained (<1mm) with occasional quartz phenocrysts. In thin section it displays typical granophyric texture with some euhedral quartz (Figure 6e). This is typical of granites which are emplaced at low pressures where a complete solid solution exists between the alkali feldspars. If volatiles are lost then the liquidus/solidus curves are raised producing rapid undercooling. Under these conditions simultaneous intergrowth of quartz and alkali feldspar occurs. The presence of angular quartz grains is typical. There are also very occasional stubby laths of plagioclase with compositions An 70%+ (bytownite). These have probably been derived from the gabbro.

The second granitic body in the Complex is found in Worsell Wood. An exposure on the north west side of the hill displays a small cliff, the top of which is made up of granite. This exposure is at around the 240m contour and similar, but smaller, bodies of granite occur all around the hill at this height. The granite of Worsell Wood differs from that of Hanter Hill. In hand specimen it appears consistently darker in colour and coarser although grain size is still <2mm. In thin section the granites of Worsell Wood differ considerably from the Hanter Hill granites (Figure 6f). They display clumps of stubby monoclinic feldspar crystals

which have compositions 70-90% An (bytownite). Plagioclase in the main body of the specimen is consistent with the Hanter granite and has a composition of around 50% An (labradorite). The groundmass shows granophyric textures, although these are less well developed than those on Hanter. This may indicate initial slower cooling within a reasonably large granitic body followed by low pressure undercooling on contact with the dolerite. This texture is consistent for granites from different sides of Worsell Wood indicating that they may have originated from a common source.

The third granite body is on the west side of Stanner Rocks. It is much the largest of the three and is again fault-bounded on all sides. In hand specimen it appears similar to the granite of Worsell Wood, although there are some differences between samples taken from the centre and edges of the main body. Samples from the edge are granophyric in texture and show secondary spherulitic epidote and some muscovite. Those from the centre of the mass have distinct quartz and plagioclase (labradorite) crystals in the groundmass with a lower amount of granophyric texture. This mixed texture may indicate either slower cooling or higher pressure compared to the Hanter granite. Secondary chlorite is associated with small quantities of biotite and muscovite. Samples from both areas display the same stubby high Ca plagioclase xenocrysts as the Worsell and Hanter granites indicating that all three granite types may be from the same source and probably the same episode.

Summary

The rock types show similarities which indicate that all three sites (Hanter, Worsell and Stanner) were formed by a common intrusive event. Strictly speaking the basic rocks should be described as meta-dolerites and meta-gabbros since they display clear evidence of retrograde metamorphism. This metamorphism shows two distinct phases:

1) The presence of the brown amphibole probably relates to a metamorphic episode which took place during the initial cooling of the Complex shortly after emplacement. It may be related to the episode involving the intrusion of the granites;

2) The presence of chlorite, actinolite, quartz and epidote is evidence of greenschist facies metamorphism.

The granites are unusual in that they appear to consist mainly of quartz and feldspar only, without the usual range of secondary minerals, such as biotite. All contain occasional well preserved high An feldspars either singly or in clumps which may have been derived from the gabbro and may indicate a common source. They are more or less granophyric in texture which indicates emplacement at low pressure. This, together with the absence of hydrous minerals, may serve to confirm that they were emplaced as the last phase of the magma and not as the result of the melting of crustal material.

The first aim of the project has been completed and the rock types and relationships have been confirmed in the field. The Complex shows gabbros and dolerites which have a common mineralogy and which have evolved from each other by differences in cooling rates, possibly as different phases of the same intrusion. The granites probably represent the final stages of intrusion, although their exact relationship with the other rock types is unproven. They do, however, contain some high Ca feldspar probably derived from the gabbro. Local relationships show that the Complex was exposed and subject to erosion by the middle of the Silurian, but lack of deposition in this area between the Cambrian and the beginning of the Silurian makes it difficult to be more precise. The next phase of this project will be to investigate the geochemistry of the Complex to establish its affinity to either the calc-alkaline plutonic rocks of southern Britain or to the more basic oceanic crustal rocks of the Avalonian of Newfoundland. The final objective will be to attempt to establish an isotopic date for the Complex based on a wide variety of rock types.

Acknowledgements

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Author

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Gypsum Karst in the Western Ukraine

James Gallagher

Figure 1. Catastrophic subsidence of a garage at Ripon.

Introduction

In May of 1999 I was lucky enough to be given the opportunity to travel to the Ukraine on business. The trip was related to the ROSES (Risk Of Subsidence due to Evaporite Solution) study of gypsum dissolution geohazards funded by the EC under the Framework IV Program. Gypsum dissolution, as reported in the national news, has caused catastrophic subsidence in Ripon, North Yorkshire (Figure 1).

My first port of call in the Ukraine was Kiev where I spent the first day sightseeing in this beautiful city. Kiev is one of the oldest cities in Northern Europe and was known as a commercial centre as far back as the 5th century. The city has been called "the city in a park" and it easily justifies this title, lying amid hills along the River Dnieper and filled with beautiful gardens, parks, churches, cathedrals and monasteries. The 11th century Cathedral of St Sophia, now a museum, was modelled on the Hagia Sophia in Constantinople and the Lavra Cave Monastery is a major place of pilgrimage for Orthodox Christians; mummified remains of monks and saints lie deep within the man-made cavern systems under the city.

Meetings took up day 2, although there was time during lunch to visit the beautifully reconstructed Golden Gate, first mentioned in chronicles in 1037AD. An overnight sleeper train was then taken to Ternopil in the Western Ukraine for the start of two days of rewarding field trips in the Podolsky region around the Dniester River.

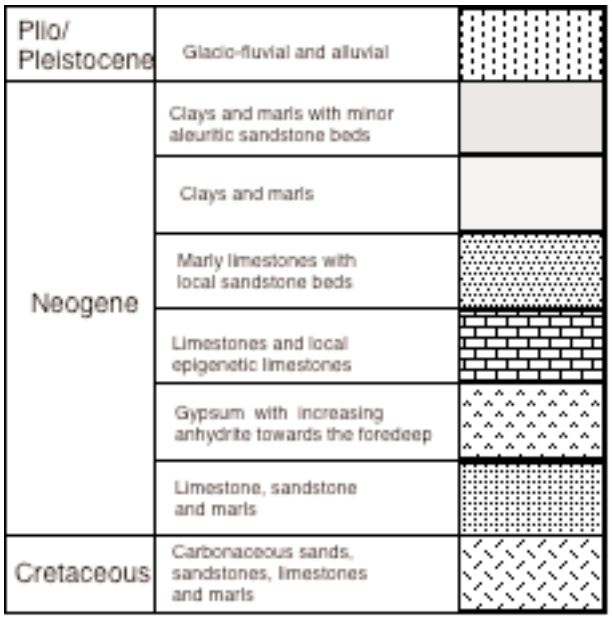

Figure 2. Generalised stratigraphy (not to scale).

Geology and the Western Ukraine Gypsum

To the north east of the Carpathian Mountains lies the Carpathian foredeep and the south-western edge of the Eastern European Platform. The area visited is within the transition zone between the foredeep and the platform. The gypsum, laid down in the Miocene, is overlain by Plio/Pleistocene glacio-fluvial and alluvial deposits, and underlain by eroded Cretaceous sediments (Figure 2). The Dniester River cuts deeply down and Devonian sediments can also be seen on the banks of some of the wide meanders.

The Miocene gypsum in the Podolsky area is most commonly divided into three distinct horizons (Figure 3). The bottom is fine-grained and microcrystalline, 0.1 – 1mm, the middle coarse and microcrystalline, arranged in domes (spherules) 1 – 100mm and the top horizon coarse to gigantocrystalline, exceeding 100mm. There are also localised epigenetic limestones above the gypsum. These are replacement limestones formed during the process of sulphate reduction of the original gypsum, caused by hydrocar-

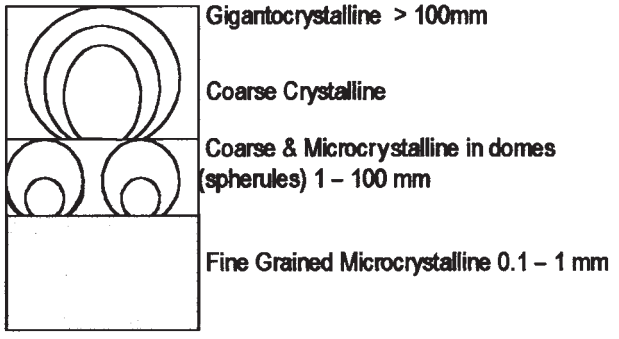
Gigantocrystalline > 100mm
Coarse Crystalline
Coarse & Microcrystalline in domes (spherules) 1 – 100 mm
Fine Grained Microcrystalline 0.1 – 1 mm

Figure 3. Gypsum sequence most commonly found in the Podolsky area (Klimchouk 1999).

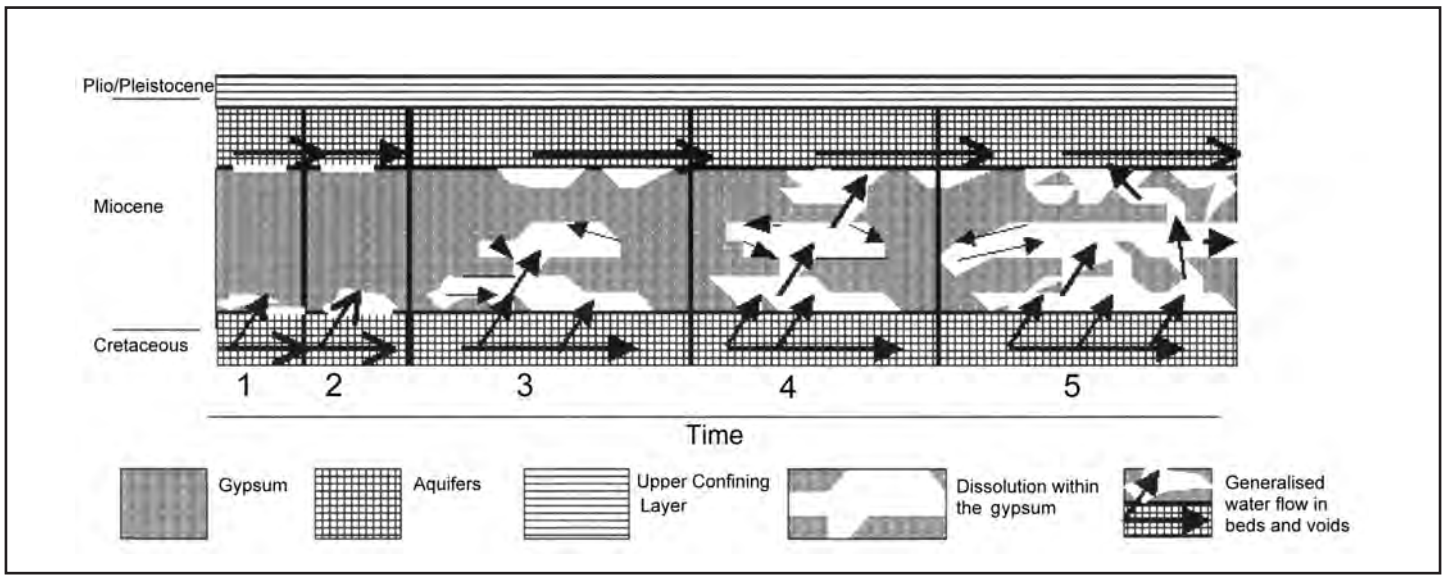

Figure 4. Conceptual model of gypsum dissolution and formation of aquifer from aquiclude with time. 1) Gypsum initially acting as a barrier (aquitard) between aquifers with dissolution occurring along the bedding planes. The clays and marls of the upper beds importantly confining the system. 2) Dissolution slowly growing at joint contacts. 3) Conduits following the joint patterns develop and extend carrying aggressive water higher into the gypsum. 4) Eventually the water from the lower aquifer breaks through into the higher aquifer and the gypsum no longer acts as an aquitard. 5) Dissolution extends forming passageways in the joints resulting in maze cave formation.

bons rising up through faults. Sulphur mineralisation, associated with the hydrocarbon migration, is also found in the area.

During the late Miocene, tectonic events in the Carpathian area created fault-bounded blocks, which subsided in a step-wise fashion from the platform edge down into the foredeep. Differential uplift during the Plio/Pleistocene and rapid incision of rivers resulted in fundamentally different structural and hydrological conditions in adjacent fault bounded blocks. These differences exacted a profound effect on subsequent speleogenesis.

The Formation of Gypsum Karst

Karst is the term used to describe surface and subsurface landforms caused by the dissolution of soluble rocks. Karst is expressed in the form of cave systems, breccia pipes, surface subsidence and surface erosion features. These features are most extensively developed and documented in limestone areas; however, gypsum ($CaSO_4$) is also soluble and gives rise to karst. Gypsum karst is less well known than limestone karst even though it dissolves more rapidly and is inherently weaker than limestone. Consequently, gypsum karst is less stable than limestone and constitutes a pronounced geohazard, especially with respect to subsidence problems.

Klimchouk (1999) proposed distinct karst types ranging from deep-seated to denuded, the formation of which depends upon many variables. The karst discussed in this paper is classed as intrastratal; that is, karst formed in confined conditions in a soluble rock sandwiched between aquifers.

Intrastratal karst is most likely to occur in artesian water environments when the gypsum bed is underlain by, or sandwiched between, aquifers. Even though the gypsum would initially have been of low permeability and would have acted as a confining unit to an aquifer, weaknesses such as joints and bedding planes (which are important to karst formation) would have allowed a hydraulic connection between overlying and underlying units. A higher water pressure (artesian conditions) in the lower aquifer would have therefore promoted the slow growth and eventual breakthrough of conduits. Once breakthrough had occurred, conduits could quickly enlarge and extend within the gypsum bed producing the gypsum cave systems seen today.

There are many variables that affect karst formation such as depth, confined and unconfined groundwater circulation systems and dissolved solids within the groundwater. The evolution of karst ultimately depends upon the solubility of the rock, availability of water under-saturated with respect to the mineral, and the rate of water flowing through the system.

Karst formation within the Ukrainian gypsum is thought to have occurred in the late Pliocene and early Pleistocene when ground water regimes were initially confined and artesian. Water flowing into the gypsum would generally have been under-saturated in gypsum and therefore aggressive. As this water flowed through the feeder conduits it would have tended to rise due to density differences causing enhanced dissolution of the roof and upper parts of the cave walls. Convecting and circulating flows, with recharge of under-saturated aggressive water from below, would form cupolas and channels in the roof initiating the later propagation of cavities to the surface.

During changes from confined to unconfined water conditions (due, for example, to river incision or water abstraction), lowering of the water table would occur and buoyancy would be lost within the system. These changes could initiate roof failure but any propagation of voids to ground level could have many causes. These include block and slab collapse, crumbling of beds, roof stoping and suffosion, all of which would generally follow pre-existing weaknesses. The final surface expression of the collapse depends upon cave sizes, surface sediments and perched water regimes. The result is catastrophic collapse or depressions, which migrate with time. Figure 4 is a conceptual model (simplified from Klimchouk, 1999) of intrastratal karst formation.

Karst features seen during the visit

Ozernaya Cave

On the field trip numerous subsidence depressions and sinkholes were seen with sizes ranging from a few metres to over 50m across. One such sinkhole, 40m across and 12m deep, was once an entrance to one of the largest gypsum cave systems in the world, the Ozernaya Cave with 117km of passages. Landslides, probably enhanced by seepage from perched groundwater in the terrace sediments, have recently buried the entrance to the cave (Figure 5).

Figure 5. Active sinkhole with perched groundwater causing continuous subsidence.

Optimisticheskaya Cave

Southwest of Korolivka, a beech forest covers an area of dry valley karst and a large number of sinkholes (Figure 6). The Optimisticheskaya Cave System, the second largest in the world, occurs here and is located within gypsum on the side of a large sinkhole. Streams are no longer visible within the area as the majority of water percolates down through sinkholes and buried valleys into the cave systems below.

Figure 6. Sinkholes and dry karst valley in a beech forest near to Korolivka.

At the end of the 1960's Optimisticheskaya had around 26 km of mapped passages; recent estimates are 207km and if current thinking is confirmed it may well prove to link up with Ozernaya Cave challenging Mammoth Cave in Kentucky for the title of the largest cave system in the world.

Chorny Potok Valley

In the Chorny Potok Valley, northeast of Yurkivtzy, a variety of karst forms can be seen. Gypsum crops out on one side of the valley and is faulted downwards on the other. A stream, disappearing underground into a cave system, can briefly be seen again at the bottom of a large collapse where the original collapse tube is visible (Figure 7). There are many depressions and sinkholes in the valley and on the slopes, most of which are likely to be linked to the course of the underground stream.

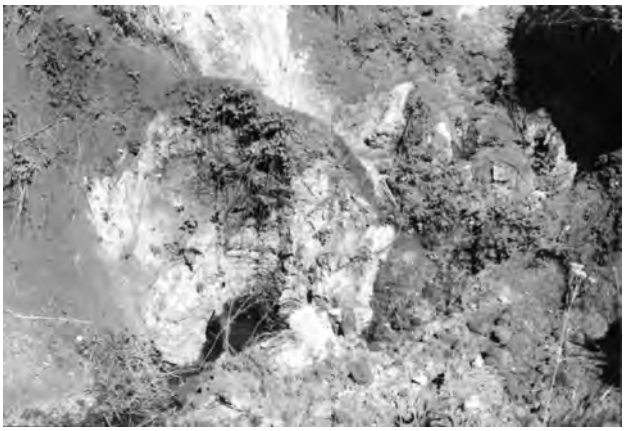

Figure 7. Collapse tube within a large sinkhole.

An Austrian First World War trench traverses the top of the gypsum outcrop and against this trench one of the depressions (3m across and 2m deep) can be seen. It was surmised that the trench was cut before the depression was manifested, therefore giving a date of later than 1918 for the subsidence. A relatively new sinkhole was spotted on the valley slope during the visit and it was confirmed that this had occurred in the last few months. It was still small, only 1.5m across and 0.5m deep with a cavity extending 1.2m down slope; this shows that the area is still very active (Figure 8).

Figure 8. New sinkhole: evidence of active movement.

Dankivtsy Collapse

In the early hours of a January morning in 1998, a collapse formed near Dankivtsy. It is said that the farm animals were agitated long before the collapse occurred; a phenomenon which has been recognised in other collapses. A 22m deep shaft was formed opening into a cave at the bottom. Dr. Alexander Klimchouk investigated this shaft and cave soon after the collapse occurred. He surveyed a water-filled passage 8-9m wide and 7m high. Loose sediments have now filled the shaft and a 20m wide by 4m deep depression is all that is now visible (Figure 9). The investigation by Dr. Klimchouk and a later geophysical survey indicated the collapse to be part of a large cave network. Interestingly, the sides of the depression show that movement of the soils and

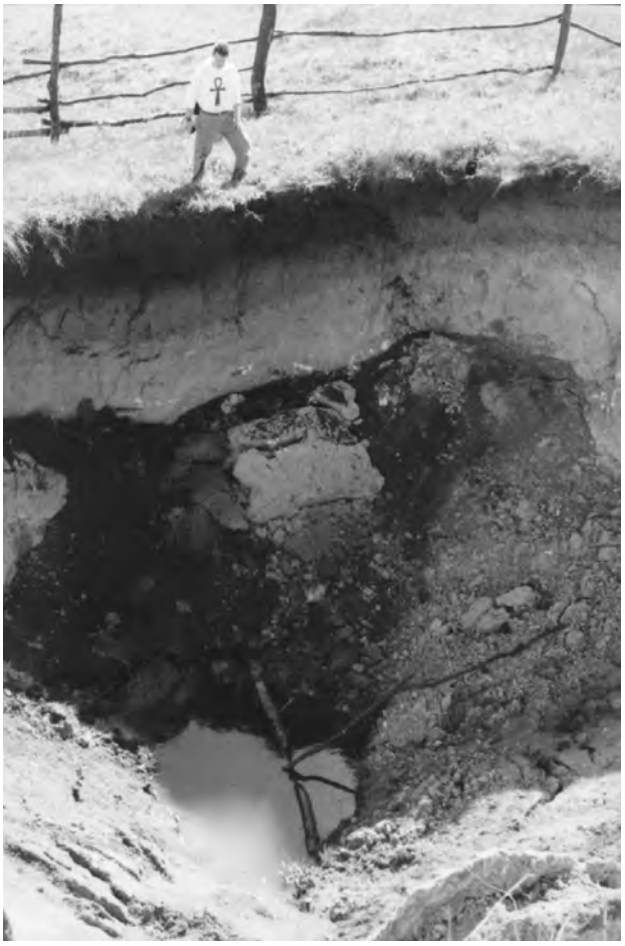

Figure 9. Dankivtsy sinkhole: now filled to within 4m of the surface with sediments.

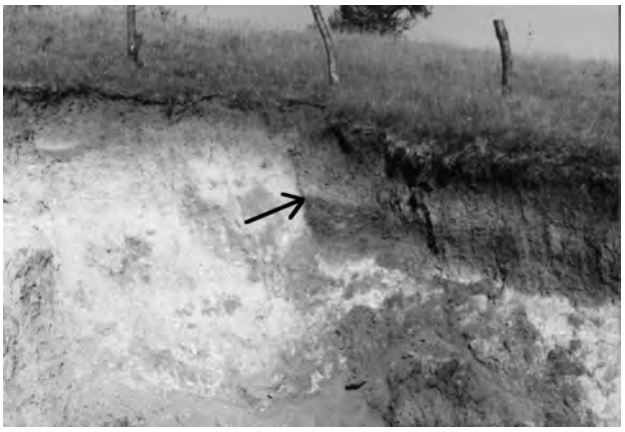

Figure 10. Evidence of previous movement within the Dankivtsy sinkhole (arrow points to sediment colour change and probable position of previous soil movement).

Quaternary sediments have occurred here in the past (Figure 10) and that a previous collapse on the same site has now become filled-in.

Mlynki Cave

The field trip also involved underground visits to two caves. The Mlynki Cave, located above the Zalissja Valley, is entered through the gypsum outcrop. The entrance passage is large and has been used to quarry gypsum in the past. Large domes of fallen material could be seen where roof breakdown has previously occurred. Once through the entrance chamber the cave quickly changed to a series of narrow passages, squeezes and climbs; our leader, Dr Klimchouk, was quick to point out that this was an easy cave! Mlynki is a true maze cave, where we would have been totally lost within 50m of the entrance without a guide.

The Mlynki Cave is now generally dry, inactive and fossilised, however, areas could be seen covered with fallen slabs and boulders from past roof failure. Secondary gypsum formations could be observed where dissolved gypsum has precipitated on the passage walls. Clay covered the floor of the passages, probably from fallen material and suffosion from the upper beds. This clay layer was only missing where feeder conduits appeared in the floors and the bottom of the passage walls. It is interesting to note that these conduits would have fed the system with aggressive gypsum under-saturated water from below during artesian flow. The exploration finished with an inspection of a well-formed cupola in an area of roof collapse where sediment movement by suffosion could also be seen. All we had to do now was find our way out!

Kristalnaya Cave

The Kristalnaya Cave (Crystal Cave) above Kryvche village was entered through an impressive gypsum outcrop (Figure 11). Looking up from the valley floor several caves were visible however, Kristalnaya was hidden within woodland. At the base of the outcrop there were many fallen boulders containing large crystals/blades of selenite up 0.5m long. (Figure 12).

Figure 11. Gypsum cropping out above Kryvche.

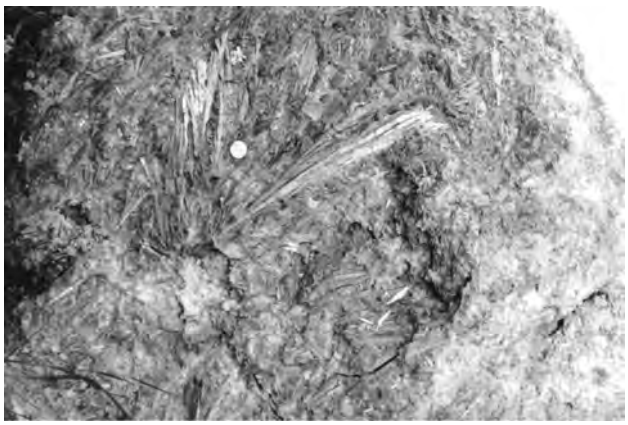

Figure 12. Large selenite crystals. Coin 20mm diameter.

Kristalnaya Cave is 22 km long and is a show cave with a lighted tourist trail of 1km. The entrance and walls of the passages are cut through large crystal selenitic gypsum; however, most of the crystal surfaces are obscured by years of wear. Deep within the cave a large fallen block, approximately 2m high by 3m across, contained a rectangular, clear, selenite crystal (200mm x 100mm) with large blades of brown selenite radiating from it. Kristalnaya is a maze cave similar to Mlynki with bottom and side passages formed by artesian flow as discussed above. The most remarkable aspects of the cave are the convection domes and channels on the roof of the passages. These clearly show how the active flow of aggressive convecting water, less dense than the gypsum saturated water, flowed at the top of the passages dissolving out the gypsum.

Conclusion

Even though, when in the Ukraine, we only visited a small part of what is one of the largest karst areas in the world, this was sufficient to reinforce ideas and models of karst mechanisms in other areas where access to the gypsum is restricted by geological barriers.

This is the case in Ripon where there is some of the worst gypsum related subsidence in England. Very little is known about the speleogenesis in this area, as investigation is only possible through drilling and limited geophysics. The visit to the Ukraine was, therefore, an opportunity to see at first hand the extreme solubility of gypsum and the ease with which karst features develop within it.

Acknowledgments

The author would like to thank Dr Anthony H Cooper and Dr John Lamont-Black for their valuable comments and special thanks to Dr Alexander Klimchouk for his comments and for his excellent leadership and hospitality in the Ukraine.

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R.O.S.E.S

Further information on the ROSES project can be found on http://www.ncl.ac.uk/roses.

Author

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Book review

Volcanic Plumes by R S J Sparks, M I Bursik, S N Carey, J S Gilbert, L S Glaze, H Sigurdsson & A W Woods, 1997, Wiley & Sons, 574pp £85.00 (hardback) ISBN 0471939013.

A masterly collaboration by seven distinguished volcanologists to produce a clearly written and wide-ranging text. The book sets the scene with a chapter describing the causes, distribution and classification of explosive volcanism and the generation of volcanic plumes. This is followed by a group of chapters which explain the physical principles and source conditions and draw these together in a physical model of the dynamics of eruption columns and does not step back from the complexities involved in applying such models to natural systems. This quantitative approach includes an excellent notation set with each chapter and explains clearly the mechanisms which control different eruptive styles.

The authors look at plume behaviour, using historic eruption case studies in comparison with their theoretical models; the nature and characteristics of pyroclastic flows and co-ignimbrite plumes which develop from them.

We tend to associate volcanic plumes with solid material but the authors cover plumes in geothermal, hydrovolcanic and hydrothermal systems, which also chart the interaction of hot magma, volcanic gases and external water in either sub-aerial or submarine settings.

In these days of concern for our atmosphere, basaltic eruptions and their plumes are of particular interest because of the amount of SO_2 which they release. The authors deal with the environmental effects of high magnitude eruptions and the mechanisms involved in dispersal of plume products in the atmosphere, as well as the techniques and uses of remote sensing for volcanic plumes which are "best observed from a distance" in the words of the authors.

Tephra fall gives us a record of past geological explosive volcanism and the features of such falls can give a safer determination both qualitatively and quantitatively of the history of explosive volcanic activity of a given volcano or volcanic area. Aggregation is also an important aspect of tephra development covered by the authors, using evidence from eyewitness accounts of eruption, field evidence of ancient deposits and laboratory experimentation which enable workers to interpret the interactions of atmospheric conditions and volcanic eruptions.

The book finishes with two chapters which look at the environmental hazards and atmospheric effects produced by volcanic plumes. Plumes migrate transporting huge quantities of material which affect vast areas of land and large volumes of the atmosphere with possible severe consequences for humans, animals, vegetation and climate change. Many lessons have been learnt since the Romans recognised the climatic effect produced by volcanic eruption, but much remains to be done especially with regard to aircraft safety.

The book has graphs and diagrams that are clear and well-related to the text, while the black and white photographs convey a strong sense of the magnitude and atmosphere of volcanic plumes.

A superb, but very expensive, addition to the library of anyone who has a strong interest in volcanological "state of the art". Selected chapters make a good top-up for S236 and S339, whilst those with a keen interest in the environment and climate would find the last chapters of particular interest.

Diana Smith BSc Hons (London) BA Hons (Open) OU Tutor

Stripped bare in Fuerteventura: An introduction to the geology and guide to selected field locations

Duncan Woodcock

Introduction

The island of Fuerteventura lies at the eastern end of the Canary Island archipelago. In common with the other islands it displays recent volcanic activity; however, Fuerteventura is unusual in that uplift and erosion have exposed the underlying basement in the west of the island. It is thus possible to study the complete evolution of the island, from the pre-existing deep ocean sediments through to the Recent subaeriel volcanic features.

This paper is the result of a two week intensive solo visit to the island in March 1999, following a study of some of the rather scattered literature available. Despite the geological interest of the island, there appears to be no English language geological introduction and field guide to Fuerteventura; I hope that this paper goes some way towards filling this gap.

Fuerteventura is an ideal location for geological fieldwork. Good, inexpensive accommodation is readily available at one of the tourist centres on the island. The main road system is excellent and carries little traffic, so one can travel easily to areas of geological interest. Although it can sometimes be cloudy and wet in the mountains, the climate is generally dry and sunny and it is possible to have long, productive days in the field. Outcrop exposure is generally excellent along the coast and in the rugged mountainous areas. Elsewhere the terrain tends to be mantled with a whitish travertine deposit; however, there are good exposures in the many recent (EC funded) road cuts and in particular in the many "barrancos", where the passage of sediment-laden water from infrequent but torrential rainstorms has scoured the underlying bedrock to produce some beautiful exposures.

Geological Overview

Figure 1 presents a simplified geological map of Fuerteventura. There is a fundamental division between the basement or " Basal Complex" (Fuster *et al* 1980) which outcrops in the west of the island and the overlying "Basalt Series".

(a) Basal Complex

The oldest rocks exposed comprise late Jurassic to late Cretaceous sediments that were deposited in a passive continental margin environment. These sediments are mainly distal turbidites and are particularly well displayed around Ajuy (Itinerary 1). Uplift of the ocean floor above the Carbon Compensation Depth during the mid Cretaceous resulted in the onset of calcareous pelagic sedimentation (Robertson & Stillman 1979, LeBas *et al.* 1986).

Volcanism began in the late Cretaceous, when alkaline basaltic and trachytic submarine volcanics were erupted (Fuster *et al.* 1980, Stillman 1988). Periods of explosive volcanism produced volcanic breccias, while less violent periods produced pillow lavas and associated hyaloclastites. Volcanism was spasmodic, with the volcanic rocks being intercalated with volcanic sediments. Associated intrusives included a composite pluton of syenite, gabbro and pyroxenite (the Tierra Mala intrusion) and a suite of NNE-trending basaltic dykes. In places, these rocks were subjected to intense alkaline metasomatism (fenitisation); the resulting Ajuy-Solapa carbonatite-ijolite complex (LeBas *et al.* 1986) is well exposed on the coast south of Ajuy (Itinerary 2).

A second phase of igneous activity resulted in the intrusion of a suite of basic and ultrabasic plutons (Gastesi 1970, LeBas *et al.* 1986, Stillman 1988). These consist of a variety of gabbros, pyroxenites and wehrlites in which the structures and textures of layered igneous rocks can be seen. Intrusion of NNE trending basaltic dykes continued throughout this period to produce the major dyke swarm that dominates the Basal Complex. In places the proportion of dykes is so high that the host rocks are all but obliterated. Locally there are patches where dykes represent 100% of the outcrop: these "sheeted dykes" are reminiscent of similar outcrops in ophiolitic terrains such as those in Oman and Cyprus and probably stimulated the original suggestion that the Basal Complex was an ophiolite (Gastesi 1973, Stillman *et al.* 1975). Overall the dykes represent some 20-30km of crustal extension over a period of *c*.30Ma, probably in response to stresses generated by changes in seafloor spreading direction (Stillman 1988). During this period a further phase of alkali metasomatism generated the Esquinzo carbonatite complex (LeBas *et al.* 1986), which is well exposed in Barranco de Esquinzo and its tributaries (Itinerary 7).

The stress regime that produced the NNE-trending dyke swarm appears to have relaxed in the early Miocene. A large ring complex, the Vega de Rio Palmas alkali gabbro/syenite complex, was intruded (Munoz 1970). This ring complex is magnificently exposed in the mountains between Betancuria and Pajara (Itinerary 4). Intrusion of the Vega ring complex was followed by a period of uplift and erosion. Subsequent geological development of Fuerteventura comprised almost entirely of subaeriel basaltic volcanism which is described below.

(b) Basalt Series

This series is conventionally subdivided into four sections (Fuster *et al.* 1968) as follows:

(i) Basalt Series I

This series represents the first subaerial volcanism in Fuerteventura and in general comprised an initial explosive phase, followed by predominantly effusive volcanism. Exposures comprise a large number of relatively thin, sub-horizontal flows, giving a "trap" topography reminiscent of similar exposures in the Inner Hebrides: the description "basalt tableland" (Hausen 1958) is very appropriate. In the east of the island, these tablelands have been eroded into a series of long, narrow mountains, known locally as "cuchillos", that run inland perpendicular to the coast.

The Series I basalts are displayed best on the Jandia peninsula in the SW of the island, where they produce magnificent scenery.

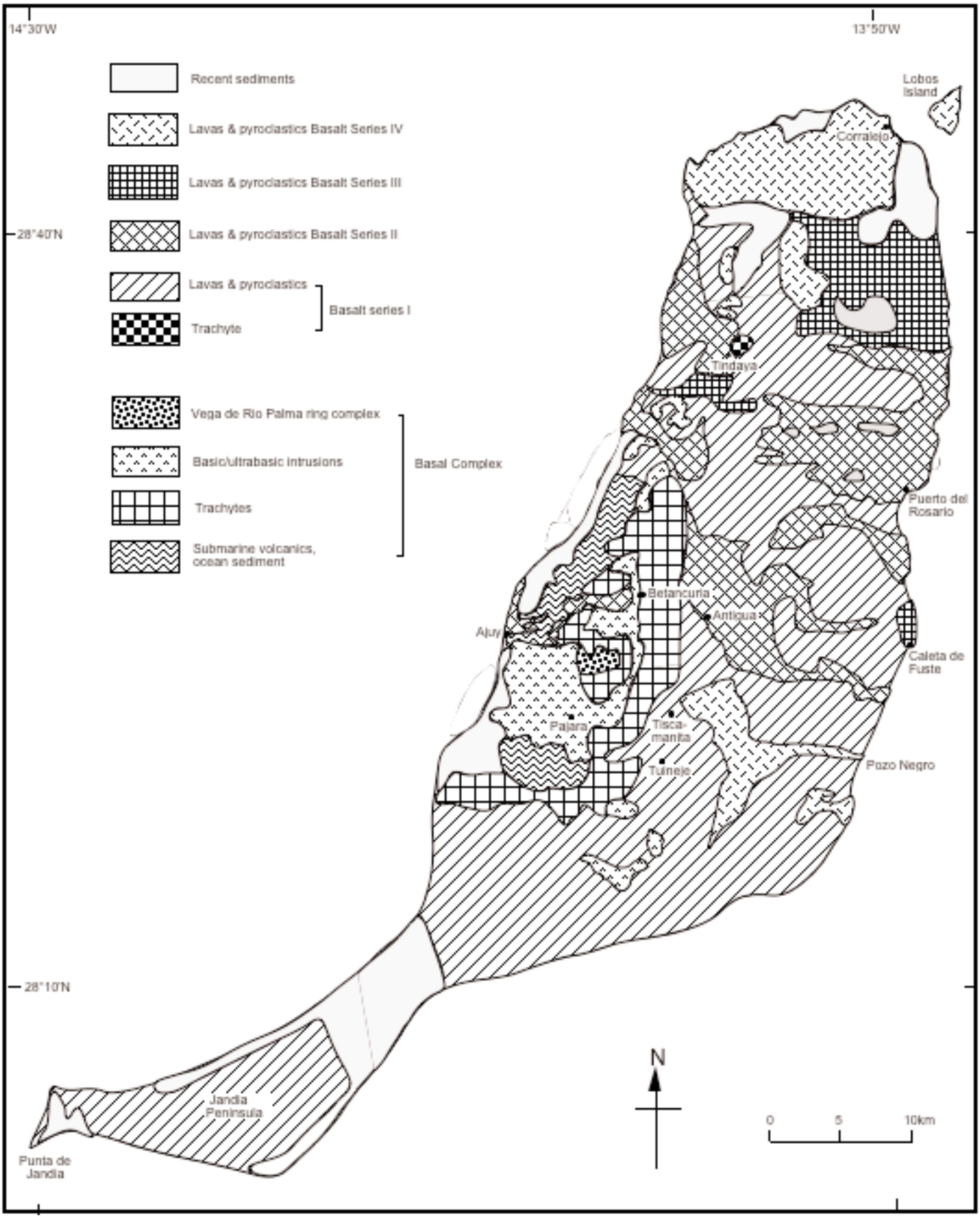

Figure 1. Simplified geological map of Fuerteventura.

Table 1. Overall chronology of geological events on Fuerteventura.

Age Ma		Event	Layered Formations	Plutons	Dykes	
	Quaternary / Pliocene	Subaerial volcanism	Basalt Series II to IV			BASALT SERIES
		Erosion	-- Unconformity --			
10	Miocene	Subaerial volcanism	Basalt Series I		Sparse dykes. variable trend	
		Erosion	-- Unconformity --			
20		Stress relaxation		Vega ring complex		
30	Oligocene			Esquinzo carbonatites		
40	Eocene	Extensional stress, permitting emplacement of NNE-trending dykes		Mafic-ultramafic plutonic suite	NNE-trending dykes intense dilation	BASAL COMPLEX
50						
60	Palaeocene			Ajuy-Solapa carbonatite Tierra Mala pluton		
70	Upper Cretaceous	First appearance of alkali basalt volcanism	Submarine volcaniclastic sediments			
80						
90		Passive continental margin sedimentation	Deep ocean sediments			
100						

They can be studied in detail on the traverse through the Jandia mountains from Gran Valle in the south to Cofete on the north coast (Rochford 1994). The basalt type is variable and usually porphyritic, with the most conspicuous variety containing large pyroxene phenocrysts. The Series I basalts are cut by a rather sparse NW-SE trending dyke swarm. These can be seen cutting through the mountain ridges and running out to sea in the coastal exposures around Punta Jandia, where a lighthouse warns shipping of the resulting hazard.

(ii) Basalt Series II

Extrusion of the Series I basalts was followed by a period of quiescence and erosion. The subsequent Series II basalts were almost exclusively effusive and are thought to have been sourced from a small number of shield volcanoes (Hausen 1958). These volcanoes have no significant topographic expression but the flows can often be seen in coastal and barranco exposures (Figure 2) in the west of the island, where they usually lie directly on an unconformity surface on top of the Basal Complex.

(iii) Basalt Series III

This series comprises late Quaternary volcanism (Fuster *et al.* 1968) displayed as a suite of scoria cones and lava flows. The lava flows are generally weathered and well vegetated inland, however, good coastal exposures can be studied immediately north of the resort of Caleta de Fuste. The scoria cones tend to be reddish in colour, the flanks furrowed by erosion gullies and the lower slopes often covered in travertine. Good examples of Series III cones are Montaña Roja, a conspicuous cone just west of the main coast road from Puerto del Rosario to Corralejo and Montaña de Tamacite, situated just SSE of the town of Tuineje.

Figure 2: Compound lava flow in Series II basalts, Llanos de la Concepcion. Height of exposure *c*.7 metres.

(iv) Basalt Series IV

This series includes the most recent phase of volcanism and is thus the best preserved. Lava flows are typically black stretches of aa or blocky lava, known locally as "malpaises", and are usually unvegetated apart from lichen growth. The best examples are Malpais Chico and Malpais Grande in the SE of the island. Scoria cones are typically black, with well developed craters. The best and most accessible examples are Gairia (Itinerary 5) in the centre of the island and the main cone on the island of Lobos (Itinerary 6). There are no written records of recent eruptions (Hausen 1958), so the volcanoes predate the arrival of the Spanish conquistadors in the 15th century.

Table 1 presents the overall chronology of geological events on Fuerteventura, and provides a convenient summary.

Itineraries

The following itineraries have been chosen to show what I consider to be the geological highlights of Fuerteventura. Itineraries 1-3 are based in the Pajara-Ajuy area and could be done in one very full day. Itinerary 4 needs at least a day, and would repay an even longer study. Itinerary 5 is a half day excursion that is best done on a clear afternoon. Itinerary 6, to Lobos Island, will occupy a full day. Itinerary 7 is a "pot pourri" of locations that can be used to fill any spare time in a day. Taken together with a day visit to the Jandia peninsula, there is more than enough for a week of outstanding geological fieldwork.

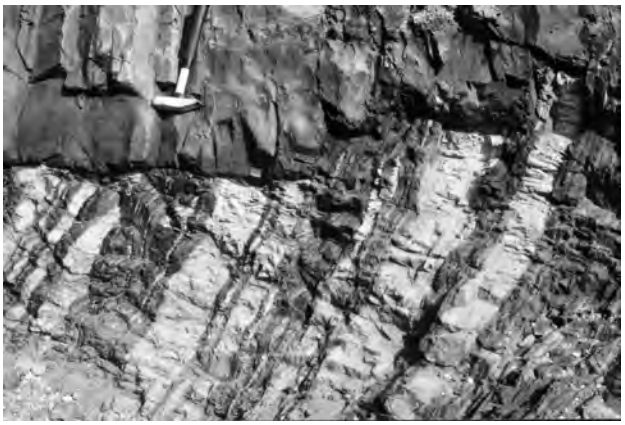

Figure 3: Metamorphosed distal turbidites cut by basalt dyke. Barranco de la Peña.

Itinerary 1: Ajuy to Barranco de la Peña
(Basal Complex sediments and dykes; Series II basalts)

Drive to Ajuy and park at the side of the roundabout at the end of the main road (28°23'54"N/14°09'10"W). The view north across Barranco de Ajuy shows outcrops of dykes in the south-facing barranco wall cut by an unconformity surface and overlain by basalt lava flows. Walk down to the north end of the beach, where an exposure containing distal turbidites cut by a series of basaltic dykes and a trachyte dyke can be studied. At the top of the exposure, the planar unconformity is covered here with calcarenites. Walk a few metres inland and then climb diagonally up the cliff by the new pathway. This path climbs up over sandstones and then onto calcarenite platforms which are well displayed immediately seawards of the path a little further north. The calcarenites are well bedded and locally conglomeratic with a variety of mainly subrounded clasts up to a metre in size. The clast type is variable, with the most conspicuous clasts being of a vesicular basalt.

When the path reaches a small square white building, branch off to the right up onto the cliff top and continue north along the cliff top until the headland of Caleta Negra comes into view. On the headland the Basal Complex below the unconformity contains several NNE trending dykes. Above the unconformity there are bedded calcarenites overlain by a massive Series II lava flow which is conspicuously pillowed at the base.

Continue along the cliff top for a further kilometre or so until overlooking Barranco de la Peña (28°24'35"N/ 14°09'20"W). At the mouth of the barranco there is an isolated stack of Basal Complex, overlain by Series II basalt. Descend to the barranco floor and walk round to the SE face of the stack, which is actually a natural arch. The pillars of the arch comprise NNE trending dykes cutting metamorphosed distal turbidites (Figure 3). There are further exposures of these turbidites in the cliffs to the south across the gravel beach.

Walk east along the gravelly floor of Barranco de la Peña for about 300-400m to superb exposures of dykes overlain by Series II basalt flows (Figure 4). The basalt flows are usually rubbly, but at one location the centre of the flow has developed massive columns. A hand specimen from a fallen column is medium grained and dark grey with green glassy phenocrysts of olivine. In thin section, the olivine phenocrysts are fresh, predominantly euhedral and up to 2mm in size. They are set in a fresh groundmass of tabular plagioclase, small pyroxene grains and opaques. From this location it is possible to climb up the south wall of the barranco and return to Ajuy by a direct route overland.

Figure 4: Basalt dykes cutting sediments of the Basal Complex; Series II basalts above the unconformity. Barranco de la Peña. Height of barranco wall *c.* 20m.

Itinerary 2: Ajuy to Punta de la Nao
(Basal Complex: Ajuy-Solapa carbonatite complex)

Follow the cliff tops south from the beach at Ajuy for about one kilometre, past hectares of undercover tomato plantations, onto the headland of Punta de la Nao (28°23'27"N/ 14°09'35"W). Along the west facing cliff, a few concrete plinths have been erected; access down the cliffs to the wave-cut platform below is possible between the second and third plinth via a rather indistinct track leading to a prominent rock overhang.

Scramble down to the wave-cut platform, which comprises grey-green submarine volcanics of the Basal Complex riddled with veins and patches of a lighter material and cut by at least one phase of thin, anastomosing dykes. The whole outcrop is cut by NNE trending basaltic dykes, typically 50-100cm thick and with prominent chilled margins.

Walk north along the wave-cut platform for about 100m, until it is impractical to go further. Here carbonatites are exposed in the west facing cliffs and in the wave-cut platform immediately to the west. In outcrop the carbonatites are white, medium to coarse grained and with a variable amount of speckling from dark minerals (Figure 5). At least some of the white grains are carbonate: they can be scratched with a knife, fizz with dilute HCl and often show a good rhombohedral cleavage. The dark minerals are biotite and a stubby black pyroxene. In thin section the carbonatites consist of a continuum of carbonate with variable amounts of a rather altered feldspar. The pyroxene displays strong blue-

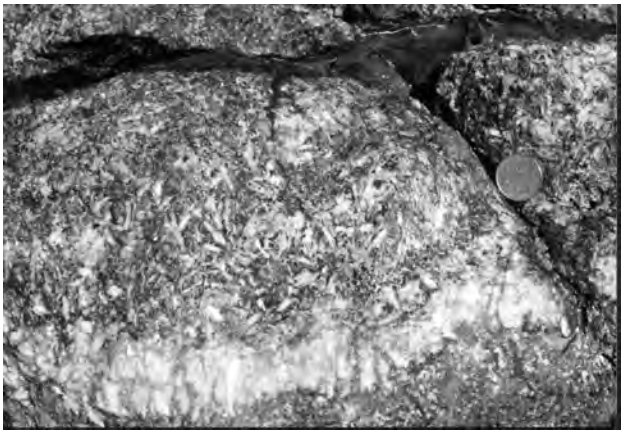

Figure 5: Carbonatite. Punta de la Nao. Coin is 25mm in diameter.

green/yellow-green pleochroism and is probably aegirine or aegirine-augite. Apatite and sphene are abundant accessory phases. The carbonatite exposures are cut by at least two phases of dykes; these are grey, fine-grained rocks with small biotite phenocrysts. In thin section feldspar phenocrysts are absent and the biotite phenocrysts are prominent against a fine-grained, rather altered groundmass; these dyke rocks are thus mica lamprophyres.

From the cliff exposures, cross a 5m wide intertidal channel to examine a 2m wide dyke containing prominent elongate phenocrysts 1-2cm long which are in general aligned with the dyke margin. This dyke trends WSW and can be followed for about 60m before being lost seawards. This dyke is symmetric about its centre line and is quite complex. The margins appear to be unchilled and comprise a zone 20-30cm wide in which the concentration of phenocrysts increases away from the margin. Careful examination of the elongate phenocrysts reveals lamellar twinning, suggesting that they are plagioclase feldspar. This can be confirmed by thin section examination, where the plagioclase phenocrysts are accompanied by occasional clinopyroxene phenocrysts in a fine grained groundmass of plagioclase, pyroxene and opaque minerals. Small amygdales appear at about 70cm from the margin, these gradually increase in size towards the centre of the dyke. Along the centre line of the dyke is a very vuggy zone, in which the alignment of phenocrysts is much less obvious. This dyke cuts the suite of NNE trending dykes, so must be younger than them. There are thus at least three phases of dyke intrusion displayed at this location.

Itinerary 3: Barranco de Pajara
(Basal Complex: mafic-ultramafic intrusions and dykes)
From Pajara, take the road to Ajuy and drive about 1km NNW to 28°21'40"N/14°07'20"W, about 100m north of the road bridge over Barranco de Pajara. Park on the east side of the road, walk back to the bridge and then down onto the wide, gravelly floor of the barranco. Walk about 200m north to where a prominent rocky gully runs west up the hillside: this is "Parada 8" of Day 2 in Fuster's guide (Fuster *et al.*,1980). Access to the gully is via a "gate" in the wire fence; the bearing of the "gate" is 320° magnetic from the most northerly arch of the road bridge.

Climb up the gully to a prominent light brown coloured trachyte dyke. This dyke strikes NNE, is about 1m thick and has prominent chilled margins. It is one of the suite of NNE trending dykes that cut the rather weathered ultramafic host rock at this locality, but is unusual in colour and mineralogy compared to the more common basaltic dykes of the suite. In thin section, the pale dyke rock appears to be rather altered but it is still possible to recognise plagioclase phenocrysts up to 3mm long. The most conspicuous feature in thin section is the sub-parallel alignment of the groundmass feldspars, especially when this "trachytic" alignment wraps around a phenocryst. The ultramafic host rock is rather weathered but it is possible to find patches of relatively fresh rock. A hand specimen of this fresh material is noticeably dense and contains prominent black pyroxene grains. In thin section, the modal composition is dominated by large clinopyroxene grains up to 10mm long. There are lesser amounts of olivine and opaques, while plagioclase is restricted to small interstitial locations. The ultramafic host rock is thus an olivine pyroxenite.

Return to the parking place and walk south along the track in the barranco for about 500m to prominent bluffs on the east side; this is "Parada 7" (Fuster *et al.* 1980). The south end of this exposure comprises rather heavily weathered pyroxenite. Northwards the outcrop becomes less weathered and has the occasional pegmatitic vein. Veining increases to a maximum at the north end of the outcrop, where it produces a rather "gneissic" texture. This exposure has been interpreted by Fuster (Fuster *et al.* 1980) and others to be a contact between an ultramafic intrusion to the south and an earlier mafic intrusion to the north, with the veining and "gneissic" texture produced by metamorphic recrystallisation (with local anatexis) of the older mafic intrusion.

Itinerary 4: Vega de Rio Palmas-Pajara road section and Vega-Buen Paso
(Vega Ring Complex and surrounding rocks)
The Vega ring complex is well exposed both in the winding mountain road from Vega de Rio Palmas to Pajara and in the bed and gorge of the Barranco de la Peña between Vega de Rio Palmas and Buen Paso. Both traverses are well worth doing and repay careful study.

Figure 6 is a sketch map of the relevant area, combining logistical details with the solid geology and is based on figure 11 in Fuster's Spanish itinerary (Fuster *et al.* 1980), supplemented by my own observations. A small party comprising one or two cars could tackle the road traverse by parking in turn at the parking places and walking to nearby points of interest. For a large party this would be impractical and it would be best to split the parking between Vega de Rio Palmas and Pajara and to walk the whole traverse (about 10km), exchanging car keys en route. Note that this road can be busy between 1000 to 1600 hrs and a constant lookout for approaching vehicles, including the occasional large coach, needs to be maintained.

The traverse of the Barranco de la Peña gorge from Vega de Rio Palmas to Buen Paso is much pleasanter than the road but does not display such a wide variety of rocks. This traverse is based loosely on Walk 5 in Rochford's book (Rochford 1994); however, it is possible to walk right through the gorge and emerge at a track leading to Buen Paso, where a new tarmac road links with the main Ajuy-Pajara road.

There are a wealth of observations to be made in this area and a detailed itinerary could occupy several pages. The remainder of the notes for this itinerary are confined to a few comments on the characteristics of each main rock type.

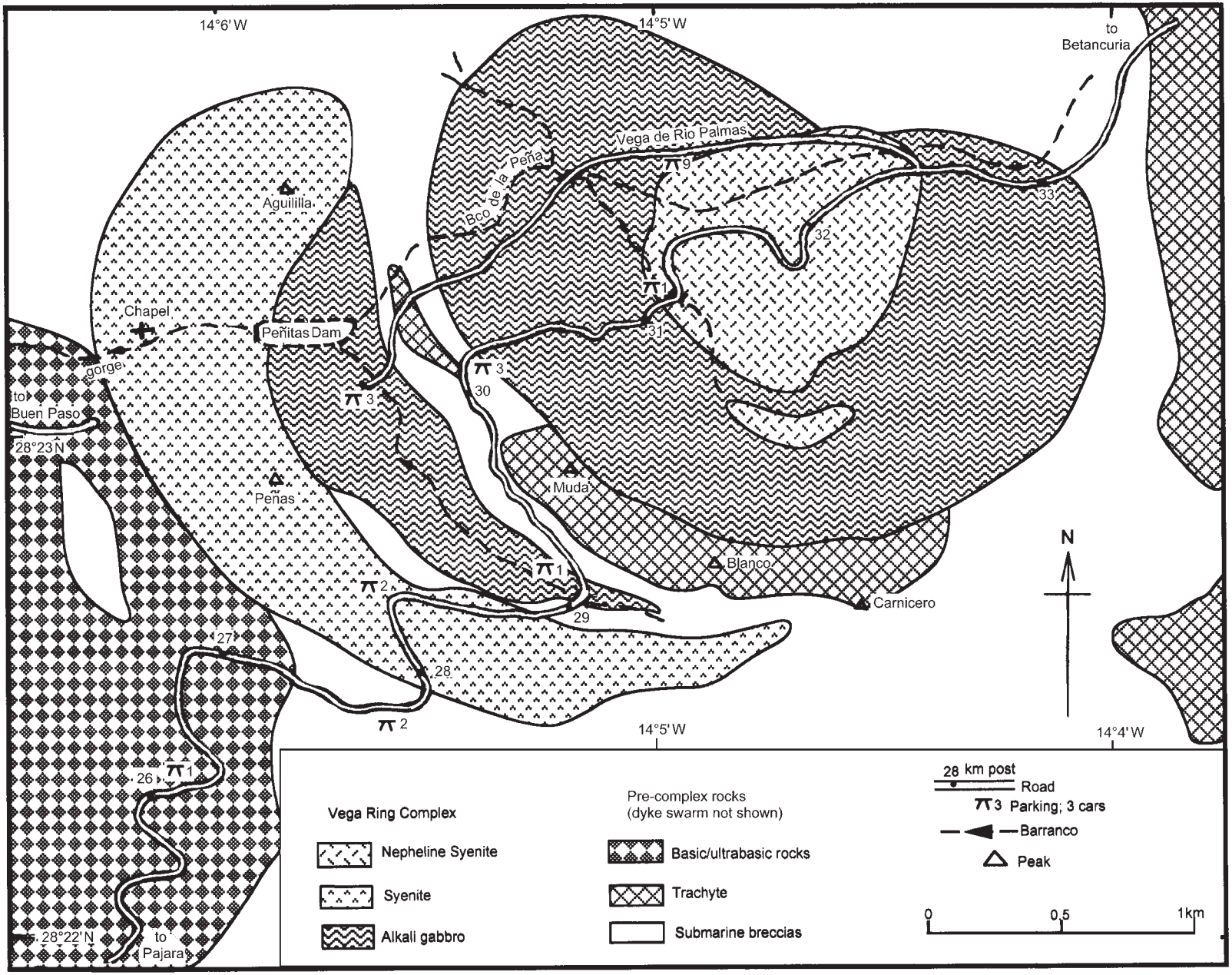

Figure 6. Geological map of Vega de Rio Palmas ring complex.

(a) Vega Ring Complex
The complex postdates the NNE trending dyke swarm, and so contains very few dykes. The principal rock types are:

(i) Nepheline Syenite
The outcrops by the roadside immediately uphill from the turnoff to Vega village are heavily weathered; however, there are good unweathered outcrops of nepheline syenite further uphill near to the contact with the gabbro. In hand specimen the nepheline syenite is a coarse grained light rock with large alkali feldspar grains showing simple twinning and with small but conspicuous flecks of pyrite. In thin section there is about 10% modal nepheline in addition to the rather altered alkali feldspar. Ferromagnesian minerals include biotite, clinopyroxene and amphibole. There are large irregular grains of sphene in addition to the opaque pyrite grains.

(ii) Gabbro
The inner outcrop of this rock type can be studied most easily in the Barranco de la Peña, where it crops out in water washed slabs. The exposures downstream of the bridge at 28°23'30"N/ 14°05'10"W are coarse grained and in places show some banding of lighter and darker minerals. The gabbro fines downstream to a medium grain size adjacent to the contact with the pre-Vega breccias. In hand specimen the gabbros comprise from 50 - 80% feldspar, with the occasional cleavage plane showing lamellar twinning when examined with a hand lens. Thin section examination confirms that the feldspar is predominantly plagioclase. Ferromagnesian minerals include biotite, clinopyroxene and a brown pleochroic amphibole which often patchily replaces or mantles the pyroxene. Sphene and apatite are common accessory minerals.

(iii) Syenite
The syenite outcrop forms a prominent semicircular ridge breached in the west by the Barranco de la Peña, which has cut a spectacular gorge downstream of the Peñitas Dam. There are superb, water washed exposures in the gorge, where the syenite can be seen to coarsen gradually away from its inner and outer margins. There are further good exposures of syenite along the ridge by the viewpoint at the highest point on the Vega-Pajara road at 28°22'38"N / 14°05'35"W. The coarse grained facies is light grey with prominent tabular grains of simple twinned alkali feldspar. These grains often define a number of polyhedral cavities or vugs in which euhedral grains of green pyroxene have grown. In thin section the pyroxene shows yellow green/blue green pleochroism; it is probably aegirine augite.

(b) Pre-Vega complex rocks
The host rocks for the Vega complex comprise submarine breccias intruded by basic/ultrabasic plutons and by trachytes. The whole suite is heavily intruded by the NNE trending dykes which in places almost completely obliterate the host rock, making study difficult.

(i) Submarine breccias
This rather unspectacular rock type can be studied in road cuts between km 29 & 30. It usually comprises angular fragments from 1 - 10cm in size, with the occasional larger subrounded block. In thin section, most of the fragments can be seen to consist of altered feldspar, usually aligned to give a trachytic texture.

(ii) Trachyte
The high crags above the road between km 29 & 30 are part of a trachyte ridge that continues NNW as a low ridge running downhill from the viewpoint near km 30 to the barranco, where it crops out in the bed. These are fine to medium grained grey-brown rocks with little detail visible except the occasional feldspar.

(iii) Basic/ultrabasics
These rocks are similar to those examined in Itinerary 3.

Itinarary 5: Gairia Volcano
An ascent of this prominent Series IV basalt cone provides an opportunity to study a variety of volcanic features as well as a superb view over the surrounding landscape.

Park in the loop of road on the east side of the main Antigua-Tuineje road at 28°22'20"N/14°01'32"W, about 2km NNE of Tiscamanita. Follow a dirt track SE, skirting a solitary large house. After about 200m, this track deteriorates rapidly and trends uphill for a further 300m, where it meets a good 4WD track running south. Follow this track for about 500m, when Gairia comes into view. After a further 500m, an area of abandoned scoria quarries is reached; from here a faint track is visible going obliquely to the left and then to the right up the side of the volcano; this track gives relatively easy access to and from the crater rim.

The crater rim is about 500m across and is breached to the SE. The crater floor is *c*.100m below the rim; it is sparsely vegetated and contains a small dome-like feature. Walk anticlockwise round the rim to the triangulation station at the highest point. From here there is a good view SSE to a line of recent volcanoes: Caldera de la Laguna, Caldera de Liria and Caldera de los Arrabales. Recent flows from these volcanoes, together with the flow from Gairia, have merged to produce the Malpais Grande lava flow which travelled eastwards to the coast at Pozo Negro. The town of Tuineje is visible just west of south, with the cone of Montaña de Tamacite just beyond. Tamacite is an older Series III cone as evidenced by the numerous radial erosion gullies on its flanks. To the west are the rounded hills and mountain ridges of the Basal Complex around Betancuria and Pajara. These contrast with the more angular basalt cuchillos to the east.

Walk back to the access point on the crater rim and then clockwise round the rim for about 200m to a recently landslipped area, where the "stratigraphy" of the cone can be studied. The outcrop comprises crudely bedded scoria, dipping outwards at about 50°. Clasts are typically 10-50cm in size and variably vesicular. Many of the scoria clasts were evidently hot and plastic when deposited: there are numerous examples of sags, folds and welds. Locally there are thin, discontinuous lapilli beds and vesicular lava flows. A thin section cut from one of the denser lava samples has about 50% voidage with a wide range of vesicle sizes. The rock is fresh with a fine grained groundmass and small olivine phenocrysts.

Return to the access point on the rim and climb down carefully to the quarried area and 4WD track. There are several good examples of volcanic bombs, with "aerodynamic" shapes acquired during their flights, lying on the scoria by the path (Figure 7).

Itinerary 6: Lobos Island
Series IV basalts: scoria cones and "hornitos"
Lobos Island can be reached by boat from Corralejo Harbour. The island is worth a visit to study the variety of recent volcanic features present. Much of the eastern side and centre of the island is

Figure 7: Upper and lower surfaces of a volcanic bomb. Gairia volcano. Coin is 25mm in diameter.

dotted with small volcanic edifices known locally as "hornitos" (Rochford 1994). These range from cones of loose scoria through to edifices consisting predominantly of lava flows. Table 2 below gives the location of a few representative types.

Location (lat/long)	Description
28°44'07"N/13°49'00"W	Large scoria cone, no lava flow visible
28°44'23"N/13°48'53"W	Small scoria cone, lava flow on flank
28°45'11"N/13°49'00"W	Small scoria cone; ?pillowed lava flow
28°45'21"N/13°48'16"W	Small edifice; principally blocky lava
28°45'22"N/13°49'15"W	5m high edifice, large scoria blocks, much spatter (a true hornito: Figure 8)

The west of the island is dominated by a single large scoria cone about 100m high known as Caldera de la Montana. From the summit, one can see how the sea has breached the NW wall of the crater.

Itinerary 7: Pot Pourri

The following are worth visiting if time and energy permit:

(i) Pozo Negro

The road to Pozo Negro follows the north side of the Malpais Grande lava flow. It is worth climbing one of the hills immediately to the north of the road to get an impression of how the lava flow has followed the pre-existing valley.

Figure 8: Hornito. Lobos Island. Height of exposure c.5 metres.

(ii) Betancuria

The barranco immediately to the south of the village cuts through a large outcrop of gabbro which is part of a small igneous complex that intrudes the submarine volcanics of the Basal Complex (Fuster *et al.* 1980). Access is easiest from the north end of a new plaza accessed by a tarmac road opposite a bus stop. The low cliffs (28°25'23"N/ 14°03'20"W) on the west bank of the barranco comprise a grey, medium to coarse grained gabbro with a conspicuous spotted appearance due to the development of large pyroxene crystals. In thin section, large tabular plagioclase grains are visible together with a clinopyroxene that is altered in places to a brown pleochroic amphibole. There are small amounts of biotite and an opaque mineral present. The gabbro is cut by a number of dykes of a lighter, finer grained rock which sometimes "shoot" anastomosing veins into the gabbro. These dykes are typically 30-70cm wide, have no obvious chilled margin and trend N-S. Thin section examination of this dyke rock shows that it is syenitic, with alkali feldspar predominating over plagioclase. In a couple of localities the gabbro and the lighter dykes are cut by grey basaltic dykes trending NNW with a thickness of 50-70cm and prominent chilled margins (Figure 9). In thin section these basalts are rather altered with all ferromagnesian minerals chloritised and with only an occasional plagioclase grain recognisable.

Figure 9: Syenite dyke (light) and basalt dyke (dark) cutting gabbro. Betancuria village. Note the prominent (darker) chilled margins on the basalt dyke.

(iii) Llanos de la Concepcion-Playa del Valle

There are a couple of interesting exposures along this road as follows:

(a) Submarine breccias: 3.4km down road (28°28'48"N/ 14°03'20"W).

This location is "Parada 13" of day 3 of Fuster's guide (Fuster *et al.*1980). The exposure comprises a road cut through a polymict breccia containing angular to subrounded clasts of a wide size range and variety of lithologies. The outcrop is cut by at least two phases of dyke intrusion.

(b) Dyke and basalt lava flow: 5.7km down road (28°29'14"N/14°04'37"W)

Park by the bridge over the barranco and walk about 200m NW along the barranco floor to superb water washed outcrops comprising almost 100% dykes, all with a NNE trend. This is a good place to study the complexity of the Basal Complex dyke swarm; there is a variety of dyke lithologies, chilled margin polarity and cross-cutting relationships displayed. About 200m further on the Basal Complex outcrops are truncated by an unconformity and a local depression in the unconformity surface is filled with a basalt flow that is pillowed near its base.

(iv) Carbonatite complex, Barranco de Esquinzo and tributaries.

This location contains sporadic outcrops of carbonatite and is worth visiting to enable comparison with the Punta de la Nao outcrops (Itinerary 2) to be made. Access is from the village of Tindaya via a dirt track which starts about 100m NW of the transformer station. The track skirts the SW flank of the trachyte intrusion of Montana Tindaya and could be driven along for 2km before setting off on foot across open country to the confluence of Barranco de Esquinzo and Barranco de Agua Salada (28°37'15"N/13°59'34"W). Walk up Barranco de Agua Salada for about 600m, past two earth dams, to a confluence with an unnamed stream flowing in from the east. About 50m further up the Barranco de Agua Salada, at 28°37'25"N/13°59'10"W, there are exposures in the barranco bed that are very altered and cut by veins of carbonatite. This whole exposure is cut by at least two phases of dykes. Other, less spectacular, outcrops with veins of carbonatite occur intermittently for a further 500m upstream.

Acknowledgement

Many thanks to Peter Golding, a fellow OUGS member, who provided me with a copy of Fuster's field guide and pointed me towards other useful references.

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Maps

(a) Topographic

Servicio Geografico del Ejercito 1:50000 series:

Sheet 46-40 (1.095) Tuineje

Sheet 46/47-38 (1.086)(1.087) La Oliva

(b) Geological

Instituto Geologico y Minero de Espana: Fuerteventura. 1:100000. 1968

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Book review

The Physics of Explosive Volcanic Eruptions by J. S. Gilbert & R. S. J Sparkes (eds), 1998, The Geoloogical Society, 186pp, £59 (hardback) ISBN 1862390207.

This book consists of 8 chapters by different authors each with extensive references. Gilbert and Sparkes do Chapter 1, 'Future Research Directions' themselves. I have only taken physics to 'O' level and that was 25 years ago, so unsurprisingly I found 2 chapters unreadable. These were 'Vesiculation in Silicic Magmas' and 'Tephra Dispersal' which were mostly equations. The other six chapters I could understand so potential readers should not be put off by the word "Physics" in the book title. The final piece, 'Pyroclastic Density Currents', would be very helpful to anyone looking at the products of explosive volcanism as it explains which features characterise pyroclastic flow, pyroclastic surge and ashfall deposits. The middle chapters on 'Conduit Flow and Fragmentation', 'Gas Loss Through Conduit Walls During Eruption' and 'Volcanic Eruption Columns' were fascinating and discussed processes I have never thought about at all.

However, at £59 for less than 200 pages this is not a cheap book. It is not coffee table reading material either as it lacks colour pictures and monochrome shots of volcanic explosions are not the same. Unless you are a volcanologist or are better at physics than me (not much to ask I appreciate) it is probably better to get your local library to lend you a copy rather than buying it. If you do find eruptions exciting you should read it somehow. I personally think it would be worth the money if it had colour photos of the eruptions and deposits featured in the text.

Heidi Barnes BA (Open) BSc Hons (Open)

A visit to some lesser known geological sites in the United States ofAmerica

Gladys Dinnacombe

1. Olean Rock City, New York State

While visiting the US last year I had the opportunity to visit a 'park' called Olean Rock City. I had been told that it was a very interesting place and well worth the visit, even though the 'park' is a commercial enterprise so there was an entrance fee to be paid. Rock City has been an attraction since 1890, first operated by a traction line company. Originally there was a hotel, pavilion and train station but these have long been gone but there is a great deal of information about the history in the small museum attached to the park.

This area has one of the largest exposures of quartz conglomerate in the world. The rocks here were formed during the Pennsylvanian Period around 320Ma ago. They represent river and delta sediments which were deposited on the eroded surface of Devonian shales. To the southeast of this area are crystalline igneous and metamorphic rocks with many quartz veins which were exposed at some time during their history. Long transportation of the sediments enabled weathering and erosion of the non-quartz minerals. These rocks are now on a slope together with the Olean conglomerate and they are sliding downhill on the soft shales, together forming 'Rock City' with its streets and alleys (Figure 1 a-c).

Once through the entrance, I followed the signposts across what was very similar to a limestone pavement but with giant steps needed to cross it. These crevices and joints may have formed during the collision of North Africa and the North East USA during the Appalachian Orogeny in the Permian. There are other opinions regarding this and some believe that they were formed during the splitting of Pangea to form the Atlantic Ocean. Oil was discovered here and Rock City is part of the Pennsylvania fields. Massive wheels still exist and some of the wells were in use for over 100 years. The wells are no longer used and have been plugged but originally went to a depth of approximately 2000 feet. The trail led down a very narrow gap between several large boulders and wound its way around and down a steep slope. Each of these giant boulders and cliffs had been given a name to describe it, such as Pulpit Rock, Sentinel Rock, Moray Eel, etc. Many of the giant boulders are as large as houses and sometimes the narrow spaces between the rocks, are like streets. Hence the name of Rock City.

The area was used in years past by the Seneca Indians and some of the rocks are named after them. It is believed that they may have used it as a fortress at one time. When I reached the top I went over to Signal Rock where the view was tremendous. The vista stretches for at least 35 miles each way and it is believed that here was the place where the Seneca signalled to their friends.

The geology of this area is all of great interest. During the Devonian, most of Western New York State was under an ocean, a shallow, salt-water sea. Over many millions of years, layers of sediment were laid down with more layers of sediment accumulating on top of them. During the various upheavals which followed, the stress lines in the rocks were forced open by water and ice, gradually breaking open the rock beds into large megalithic chunks. The rocks at Rock City are about 50 million years younger than other similar rocks in the Rock City State Forest north of Rock City which form similar spectacular viewing but are formed from the Salamanca Conglomerate which consists of quartz and gravel cemented together with sand and limestone.

2. Letchworth State Park, New York State

This area is known as 'The Grand Canyon of the East'. It is 15 miles long, around 1.5 miles in width and covers 14,000 acres. The canyon has been formed by the progress of the River Genesee, flowing northwards from Pennsylvania to Lake Ontario. The river runs through the entire length of the park and on its way has gouged out three very impressive gorges.

The rocks are sedimentary, consisting of shales, siltstones and sandstones, and were deposited in a shallow inland sea during the Devonian between 360 and 350Ma ago. As well as erosion, the strata were affected by at least four periods of glaciation. When the glaciers retreated, they left behind huge deposits which blocked the original route of the river. The new river route is the one which carved out 'The Grand Canyon of the East'.

Although the park is 15 miles in length, the river itself is 22 miles long, as it twists and turns, sometimes seeming to go back on itself and causing confusion in one's sense of direction. The canyon at the southern end of the park, 'The Portage Canyon', is 3 miles long, about 1000 feet wide and has an average depth of 200 feet. The second canyon, 'The Great Bend Gorge' (Figure 1d), is a little longer, wider and deeper. These two canyons are separated by a 1.5 miles long 3500 feet wide valley called 'Lees Landing'. The third canyon, 'The Mount Morris Canyon' at the northern end of the park, is 7.5miles long, about 2000 feet wide and 300 feet deep.

Canyons such as these provide spectacular waterfalls and Letchworth State Park is no exception. There are three main waterfalls on the Genesee River and many more spectacular falls on the tributaries that drop over the gorge and into the Genesee River. The three main falls are known as the Upper, Middle and Lower Falls. The lesser falls on the tributaries generally have names which either relate to the shape of the fall or are Native American, as this land is regarded as sacred to the Seneca Indians.

I was unable to photograph the Upper Falls, but they are about 70 feet high with a width of 300 feet. The Middle Falls are the most impressive (Figure 1e), and are slightly higher at 107 feet and slightly narrower at 285 feet. The Seneca Indians called these falls 'Ska-ga-dee' and believed that the sun stopped at midday to gaze in awe on the falls. The Lower Falls have been divided into two separate lesser falls over the last 40 years (Figure 1f).

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Author

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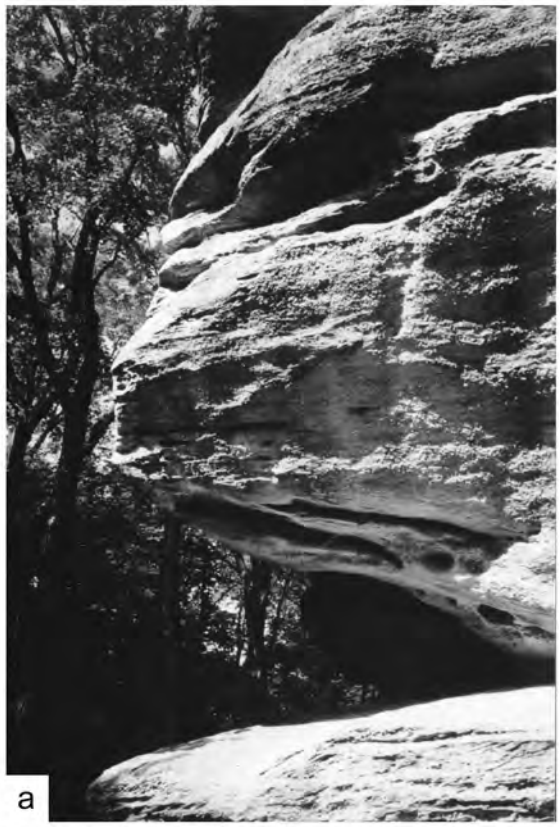

Figure 1. a) Old Man on the Rocks; b) Balancing Rock; c) Pulpit Rock showing bedding; d) View of canyon from Great Bend Overlook; e) Middle Falls; f) Lower Falls and canyon.

Ramblings of a Geology Enthusiast

Alan Stollery

Wharfedale from Bolton Abbey to Grass Wood

In my youth and up to my mid twenties I frequently cycled up Wharfedale enjoying the scenery. This gave me the idea that when I retired from work I would follow the river from Bolton Abbey to beyond where the Craven Fault crosses the valley, making notes of the geological features enroute. The walk was not done in one day but as a series of visits, each visit concentrating on a different stretch of the river. The first visit was to Bolton Abbey, then Barden Towers followed by Burnsall and finally Grassington using each of these locations as base centres.

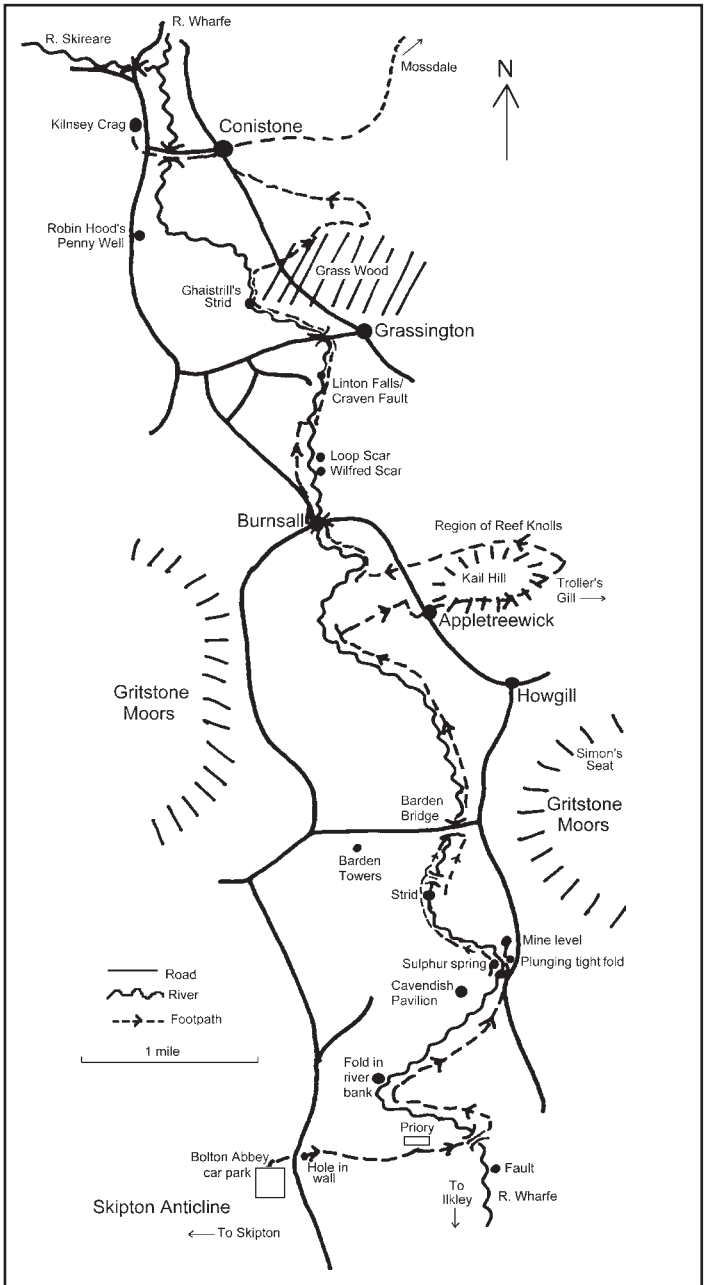

Figure 1. Plan of journey from Bolton Abbey to Kilnsey Crag.

Bolton Abbey to the Cavendish Pavilion

Map reference for start of walk SE072539.

Let us start by looking at the stretch from Bolton Abbey to the Cavendish Pavilion (Figure 1). The distance is relatively short, I would say a half to one mile, but since we have to return to our starting place the total distance will be around 1.5-2 miles.

Our walk starts at the Bolton Abbey footbridge which is reached by walking from the Bolton Abbey Car Park across the road to the small shop and houses, then following the high wall along the road for a short distance to the Bolton Abbey Estate entrance. This entrance goes under the name of the "hole in the wall".

Follow the path down the grassy slope to the wooden bridge spanning the river near the stepping stones. The wooden side of the bridge makes an excellent support to lean on if no one else is wanting to cross - this tends to be a rather rare occasion. Lean on the downstream side and look at the eastern bank.

There is a prominent exposure of Bowland shales about 15m high and 100m long rising out of the bank. The shales are steeply inclined and show folding. The sandstone beds at the downstream end are the most noticeable thing about this exposure. It will be seen from the bridge that there is a normal fault dividing the shales and sandstones and that it runs nearly parallel to the river bank. Its fault plane is almost vertical.

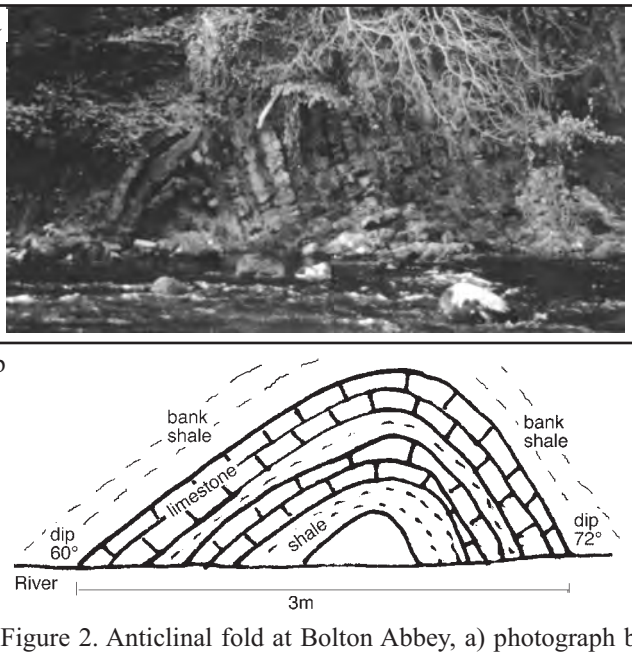

Figure 2. Anticlinal fold at Bolton Abbey, a) photograph b) sketch of bedding.

When you are satisfied in your own mind that the exposure really is a fault, walk along the east bank up river until opposite the abbey. On the opposite side of the river in the bank itself is a classic anticlinal fold (Figure 2). This is often printed in geology textbooks so I will not dwell on it other than to say it can be exam-

ined from the Abbey side should you wish to look at it more closely, but the river runs up to the fold so it is practically impossible to get close to the fold without getting your feet wet. I found it better to study this fold from the east bank (that is the bank we are already on) a few metres farther upstream but I have drawn a sketch of what the anticline looks like from the river bank. The river makes a pronounced bend in this region with the fold at the apex of the curve or meander.

On the upstream part of the meander the northern limb of the fold can be found in the river bank as successive highly inclined beds (Figure 3). Some beds are of sandstones or shales whilst others effervesce (fizz) when hydrochloric acid is dripped on them, i.e. they are limestone.

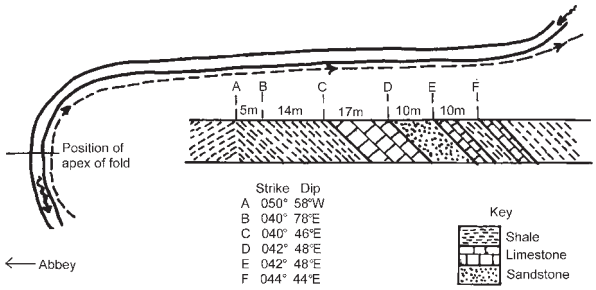

Figure 3. Distribution of the inclined beds along the eastern side of the river upstream of the fold.

The next region of interest is centred on the Cavendish Pavilion which is about half a mile upstream of the abbey.

Downstream of the Pavilion bridge the path crosses an open field (we are still on the eastern side of the river) and in the bank are a series of inclined outcrops, some of limestone and others of a dark grey / black shale. Parts of the exposed limestone contain a jumbled assemblage of crinoid stems (Figure 4). Bands of chert are also in evidence.

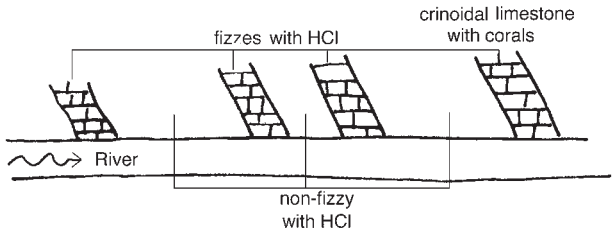

Figure 4. Plan view of inclined outcrops in the river bank downstream of the Pavilion Bridge.

Up river of the Pavilion, which incidentally serves as a small cafe, both banks of the river hold features worthy of a visit, so first continue along the east bank for about 150m or so and look at the rocks making up the bank. There is an exposure of bedded limestone appearing as a fold. Although it is folded it may also be interpreted as showing a fault which seems to be due to thrusting. This exposure was examined during an Open University Geological Society field trip and the eventual conclusion was it represented a tight plunging fold, the sides of which had been partially eroded away but part of the top of the fold was still intact. This is the best explanation so far and is probably the correct one, but it still leaves a question mark in explaining the abrupt change from almost vertical to horizontal strata which seem to exist side by side. I have tried to draw a cross section of this exposure (Figure 5). Have a look at this exposure and see what you think.

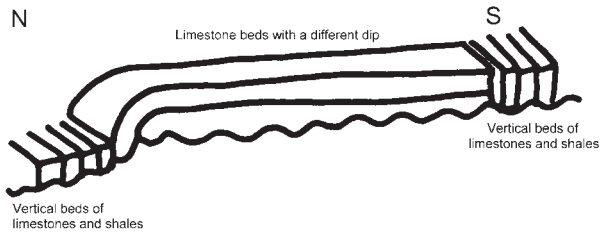

Figure 5. Limestone arch fold seen near Bolton Abbey cave.

Immediately upstream of this exposure is an outcrop of faulted limestone making a small rise in the path. Follow the path over this rise and on its far side look down the bank. There is a short, steep climb down from the path to the river. This leads to the entrance of Bolton Abbey cave (Figure 6).

I read of this cave many years ago in a local geology book which located it as upstream of the abbey on the right bank near water level and for years looked for it immediately upstream of the abbey on the right hand bank and of course could not find it. In reality it is considerably upstream of the Abbey and on the left bank. The author must not have realised that convention relates the banks of a river as looking downstream, not upstream. This is why I try to refer to banks as N, S, E or W and if not I state whether viewed upstream or downstream.

However, returning to the cave; first, it is not a cave but a trial mine level. It is about 25m long and can be groped to the end without lights. With the aid of a torch, specimens of calcite can be seen to be abundant in the roof and walls and in UV light most glow blue but some are yellow. There is no galena or comparable mineral. The level runs into the small rise over which the path climbs.

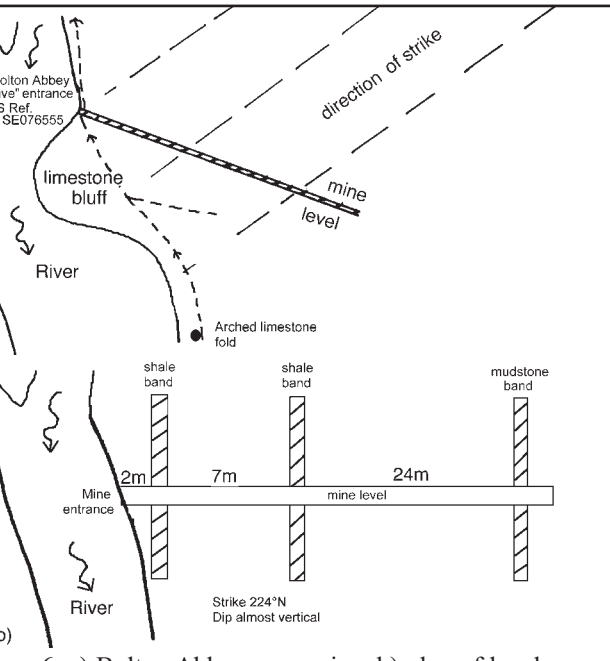

Figure 6. a) Bolton Abbey cave mine, b) plan of level.

This is the limit of the walk upriver for this section but whilst we are here we might as well have a look at the start of the next section as far as the sulphur spring and the beginning of the gritstone exposures. It means returning to the Pavilion bridge, crossing over to the Pavilion then walking a few tens of metres up the west bank of the river. Details are given in the next stretch, namely, "Cavendish Pavilion to Barden Bridge".

Cavendish Pavilion to Barden Bridge

Map reference for start of walk SE078553
Having looked at the mine level, return to the Pavilion or, if starting the walk from the Pavilion, park your car at the car park near the Pavilion and take the footpath up the west bank of the river.

After a few metres there is a branch in the path which leads to the edge of the water. Very near this branch and after we have left the main path a small very clear pool can be found tucked away at the side of the path. The pool side and bottom are coated with a white sulphurous deposit created by bacteria in the pool. This pool is the Bolton Abbey sulphur well or spring and the strong sulphur smell is a consequence of bacteria attacking the iron sulphide in the Bowland Shales. The water is so clear that I had to put my finger in the pool in order to find the surface.

A little farther along the path is a sandy beach which is almost directly opposite the mine level on the far bank. Viewed from this beach the limestone folds and faulting around the level can clearly be put into perspective.

The geology here becomes more complex since there are almost vertical strata of limestones and shale bands alongside folded beds then almost horizontal beds a little upstream. There is a complex of local faulting and folding. I have drawn a diagram to try to show my interpretation of the structure here (Figure 7).

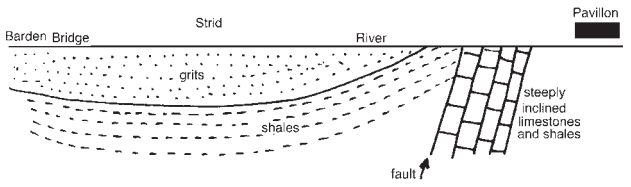

Figure 7. Suspected distribution of beds between the Pavilion and Barden Bridge.

Corresponding beds to those on the east side of the river are seen here in the path on the west side as upturned edges of limestones and shales crossing the floor of the path. A little farther on we come to an outcrop of grit bent as though part of an anticline. This is really against the general trend since we are entering a syncline which bottoms at the Strid. Upstream, the river is placid for several hundred metres until we near the Strid.

There are two Strids, namely, upper and lower. The most notorious is the Lower Strid which we have just reached. The rocks here are gritstone and higher in the sequence than the limestones and Bowland Shales previously encountered. The grits have quartz pebbles up to 20mm across randomly embedded in them. There are deep potholes scoured into the gritstone platform indicating that the river flowed over these beds at some time.

This is where a word of warning is needed for those not familiar with the Strid. There is a bravado act of trying to jump across the Strid (it gets its name from stride) DO NOT TRY IT ON ANY ACCOUNT, too many people have failed and drowned.

The jump is no great feat but two important facts must be born in mind. First, it is wider than it seems and, second, jumping from west to east is downwards, but one has to come back and it is upwards, an entirely different proposition. One slip and you are in very serious trouble and the chances of coming out alive are small.

It is not always realised that although the Strid is very narrow the whole of the river Wharfe must flow through it. Hence, the river must flow very fast or be very deep. In the case of the Strid both apply. The mean depth is supposed to be about 4m but I have read that in places the depth goes down to 12m in the form of potholes. These create whirlpools with associated "sucking down" action. However, enough said about the Strid, let us continue up the valley.

The next landmark is the aqueduct across the river, carrying water to Bradford. Here there is an exposure of flaggy grits indicating we are still near the bottom of the trough syncline. We can now cross to the east bank and walk across fields to Barden Bridge. These fields are a popular picnic spot above which, on the hillside, are outcrops of sandstone boulders.

Our return journey from Barden Bridge can be by the route we have come or by two alternative ways. The first is to walk back across the field on the east side of the river but, instead of crossing at the water pipe, continue down the left hand river path. You will arrive at the Strid on the opposite side to our previous visit and eventually arrive at our mine entrance. From here follow the way we originally came.

The other choice is to cross over the bridge where, on its western side, you will find a stile and path leading downstream and joining the path from the strid. The final variation is to keep to the road after crossing the bridge and climb up the hill to the ruins of Barden Towers. This is an old hunting lodge and is a visitor attraction.

After looking at these ruins continue along the road where after a mile and a half you should come to the entrance drive to the Cavendish Pavilion. If you had started from Bolton Abbey you will have to walk another half mile or so to the village. Take heart, it is a very pleasant walk whichever way you decide to return.

Barden Bridge to Burnsall

Map reference for start of walk SE053574.
There is a parking spot at the eastern side of Barden Bridge near the river, but it is somewhat limited and it may be necessary to park near Barden Towers instead. The walk down to the bridge is not far (Figure 8).

The first mile up the east bank starting at Barden Bridge is a pleasant riverside walk across fields but geologically somewhat inert. The main points to note along this stretch are the regions where the river periodically changes from placid to turbulent, suggesting possible changes of bed rocks. There are also some prominent mounds between the river and the road. It is not until the stepping stone near Howgill that the river loses its placid nature. Here a stream from Skyreholme joins the Wharfe and

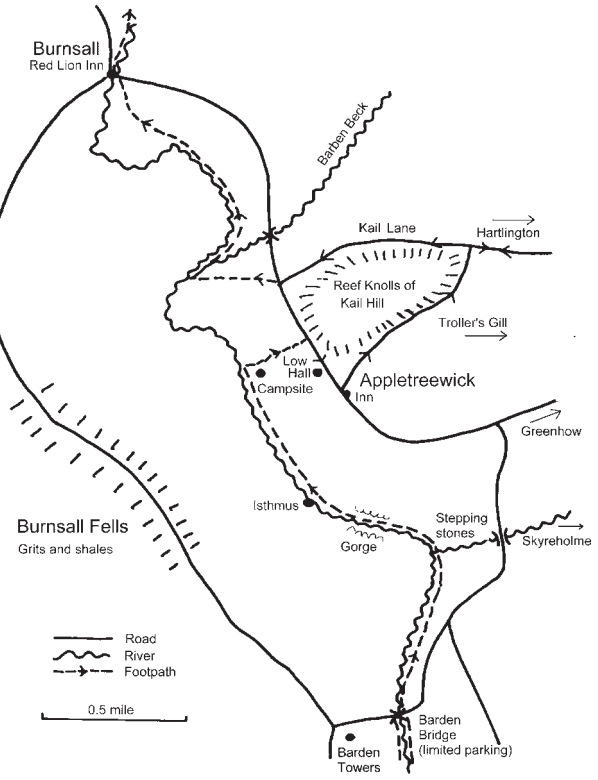

Figure 8. Map of walk from Barden Towers to Burnsall.

beyond this stream the path enters a narrow gorge where the river becomes much more turbulent.

The river takes on a different character here, becoming more violent as it cascades through the gritstone gorge. These grits have small quartz pebbles about 2mm in size embedded in the sandstone, whilst the beds develop a southerly dip of 14°S.

Farther up the gorge, ribs of grits run across the river and the dip has become 25°S. The nature of the river keeps changing from turbulent rapids to placid stretches.

As we come out of the gorge we find a rock outcrop running into the river at an angle forming a kind of isthmus. Here the pebbles embedded in the grits are much larger, up to 10mm across. The beds are steeply inclined and I suspect a fault is indicated. A diagram I have drawn summarizes this stretch of river (Figure 9).

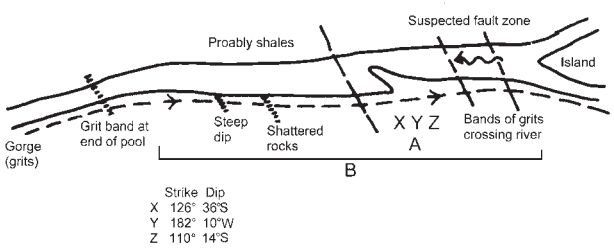

Figure 9. River Wharfe between the gorge and the campsite. A is the region at the isthmus - note the variation in strike and dip; B is the stretch from leaving the gorge to an island a little farther up river.

We are now near the village of Appletreewick and this is where we can make a small diversion around a hill at the back of the village, so look for a path which will take us from the river bank to the road. There is a way through the riverside campsite which is quite near by. At the road turn right for Appletreewick.

Behind Appletreewick is the limestone hill named Kail Hill. Our walk climbs over and round this hill, so after leaving the river bank a little upstream of the island just mentioned and following the path up to the road, turn right (i.e. down valley) at the road and head for the village of Appletreewick. Keep your eyes open for the house "Low Hall". From here can be seen a promentary of land which runs down to the grit isthmus below the island.

Turn left up a track near the inn on the approach to the village. At first the track is quite steep for a few hundred metres then levels out. There are no immediate rock exposures but the walls are limestone.

Behind the hill our path or track meets another one called Kail Lane. Near the junction with Kail Lane and a little to the east of it is an outcrop of limestone on the south side of the lane. The outcrop is well bedded and jointed.

Now head west down Kail Lane away from Hartlington. The track runs alongside Barben Beck and through a banked depression as it approaches the metalled road. Here can be found limestone exposures in the bank and a small exposure in the west side of the path. There are also exposures upstream in Barben Beck. Note that no screes are in evidence.

The hill we have just walked round is a Reef Knoll, one of a line of them which extend from here, cross the valley upstream of Burnsall then run along the southern side of the Mid Craven Fault as far as Settle.

Where Kail Lane meets the road up the Wharfe valley, the exposures of limestone are lost and instead we have a conglomerate of boulders and alluvial deposits. These deposits seem to extend right across the valley and account for the lack of rock exposures along the river bank at this region (Figure 10). The deposit is obviously glacial or alluvial and with the abrupt cover of the limestone at the foot of Kail Hill, together with the level floor of the valley, I suspect it to be the remains of one of the glacial lakes which are known to have existed in Wharfedale at the end of the Ice Age.

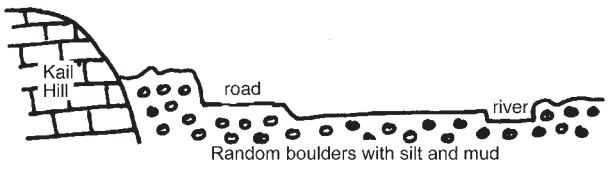

Figure 10. Sketch of section through Kail Hill and the Wharfe valley.

Return now to the river path and follow it to Burnsall. There are no rock exposures to record, even where the path crosses Barben Beck at a bridge. Near Burnsall there is a bank of the river about eight feet high but it cuts through random boulders set in mud and silt. The river deposits extend as far as Burnsall itself.

A feature to note downvalley of Burnsall is the contrast between the sides of the Wharfe valley. The east side where we have walked con-

sists of limestone knolls whereas the west side rises very steeply as Burnsall Fell and consists of shales in the lower region, capped by grits. The contrast between the two sides is quite marked (Figure 11).

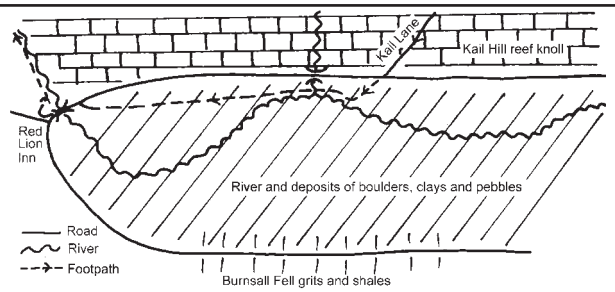

Figure 11. Burnsall valley deposits.

Burnsall to Grassington

Map Reference for start of walk SE033612.

This section is one of the most interesting parts of the Wharfedale walks since it passes through the Reef Knoll belt and crosses the Craven Fault at Linton Mill near Grassington. There is a Pay and Display car park near the bridge at Burnsall and close to the river but in quiet periods free parking can often be had on the roadside alongside the grass between the bridge and the official car park.

Our walk starts behind the Red Lion Inn at Burnsall where there is a riverside path running upriver along the west bank. There are two small islands in the river and on the NE bank is a limestone cliff about 3m high but it is on the wrong side of the river to examine. However, near the church the limestone is exposed on both sides - it seems that here a band runs across the valley.

A few hundred metres farther upstream the river passes through a gorge with good exposures of limestone on both banks and across the path run numerous veins of calcite. We are at Wilfred Scar. The river makes slight meanders for a few metres, beyond which it will be seen to emerge from another larger gorge with very prominent scars making up its banks. This is Loop Scar (Figure 12).

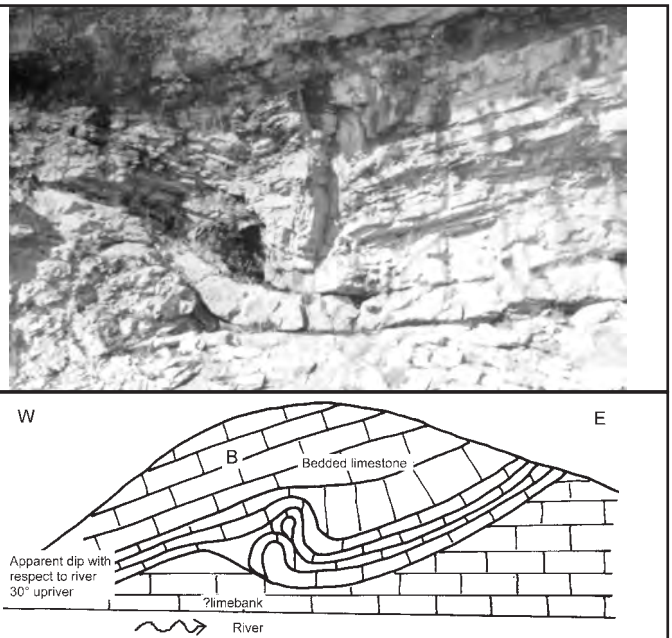

Figure 12. Loop Scar.

Stop here and study the scar on the northern (or eastern) side of the valley. Here is an excellent illustration of slumping down a steep submarine slope. The bedding runs down at a steep angle as the debris must have flowed down the slope, then loops back up to climb over a mound. The side of the reef knoll down which the debris flow took place can be easily traced and also a small mound or lime bank which diverted the flow. It has been suggested that the structure represents two separate flows rather than a single one - this is open to discussion! Yet again I have made an attempt to draw the exposure but really it needs to be seen live (Figure 12).

We are now crossing through the reef belt zone and the river varies from placid to turbulent. Soon we come to some stepping stones and a suspension bridge. Cross this bridge and note river terraces as we walk up the valley.

The next feature to note are two streams which enter the river exactly opposite each other. I suspect they are following a line of fault which crosses the valley here. On our right we eventually pass a house set on a promontory, probably a rock outcrop. This is Lythe House.

After Lythe House the bank is lacking in rock exposures. Passing the Sewage Works (not too unpleasant an experience) the bank tends to be featureless representing a flat flood plain, but eventually we find limestone boulders and limestone outcrops in the bank. These herald our approach to the Craven Fault.

You will pass a row of stepping stones leading to Linton Church. Do not cross them unless you wish to have a look at the church - as a matter of fact it is quite an interesting little building.

The presence of the Craven Fault is indicated by a cascade type waterfall named Linton Falls. They are quite a long walk from the village of Linton itself but not too far from Linton Church and Linton Mill. A footbridge from the Grassington car park crosses the river directly over the falls so an easy way of approaching them is to park at the Grassington National Park car park and walk down to the river.

Since the Craven fault is very important locally, I am going to give a more detailed account of the observations and measurements I made here (Figure 13).

My approach is from the downstream end and the start of this stretch is about 50m downriver of the bridge, where there are exposures of bedded limestone dipping in a SE direction at a fairly high angle (three readings of strike and dip being 065° 36°SE, 085° 32°SE , 082° 15°SE); please note my compass bearings are with respect to Magnetic North. I took some fixes from surrounding features and transferred them to my O.S. map in order to determine the angle between Grid North and Magnetic North. According to my calculations M.N was 8° west of G.N.

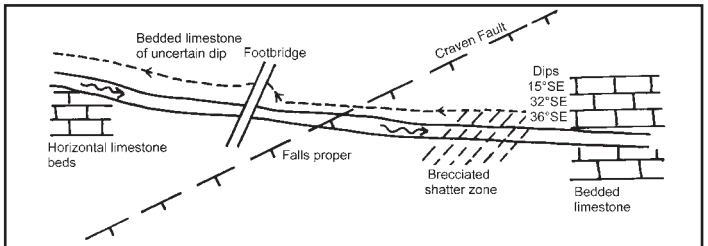

Figure 13. Strata at Linton Falls

Next came a zone of broken brecciated blocks of limestone (shatter zone) followed by large limestone blocks at the falls proper, near and under the bridge. Here the strike and dip are not clear owing to the extensive erosion of the jointing, but immediately above the bridge for about 25m the beds seem to be horizontal. This is followed by a 50m stretch where the joints and beds are so enlarged it is difficult to determine which is which.

Next there are two weirs, about 100m apart, which I presume once helped work a water wheel at the mill, and the beds here are horizontal. The river now is placid up to the road bridge and we have completed our traverse of the Craven Fault. Finally the river becomes more turbulent at the bridge which has been built on a limestone bed in the river.

We have traversed the Craven Faults and here the North and Mid faults seem to have more or less converged, but let us have a look a little farther up the valley to see if this is indeed the case. Our next stretch is from Grassington, which has a copious and convenient car park, to Kilnsey well to the north of the fault.

I found on a recent visit that a fence has been erected along the river bank downstream of the falls making access to the exposures more difficult.

Grassington to Kilnsey

Map Reference for start of walk SD998639

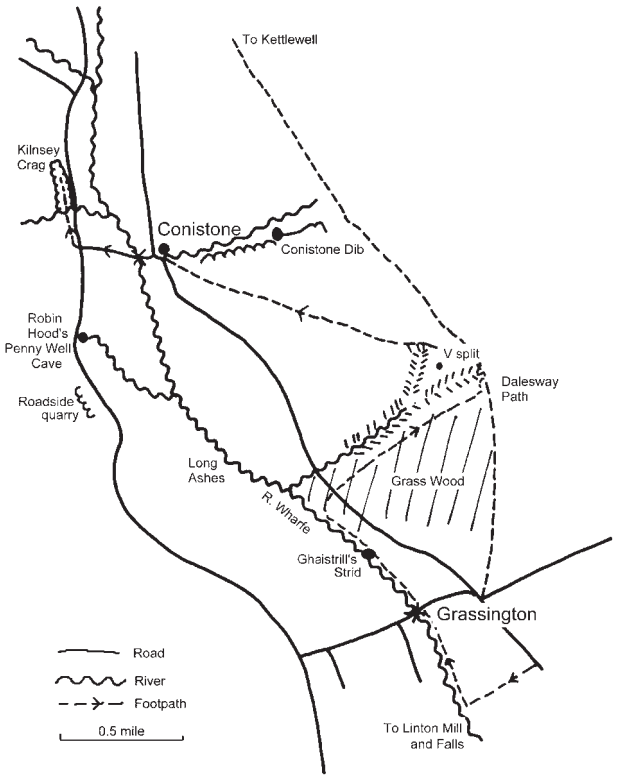

Figure 14. Map of walk from Grassington to Kilnsey Crag.

There is a change in the character of the valley beyond Grassington when it becomes completely dominated by limestone and this is particularly noticeable after the next 200m or so.

We are starting the walk from where we finished on our journey from Burnsall (Figure 14), so walk from the Grassington National Park Car park down the path to Linton Falls, then go upvalley along the river bank to the bridge carrying the road from Threshfield to Grassington. The path continues from the east side of the bridge across a field alongside the river.

Above Grassington bridge the river is placid until Ghaistrill's Strid is reached at the start of Grass Wood. Just before Grass Wood there is a seat on the river bank where the Wharfe runs through rapids in a narrow shallow limestone gorge. Here the river has cut a course through a band of bedded limestone for about 100m or so. The dip is about 4-5°SE and so can be regarded as nearly horizontal. A platform of limestone crosses the river at an angle and contains well formed clints and grykes.

The river is in a small gorge with gentle curves and it cuts through a promentary which crosses the valley floor. The road on the opposite side of the valley climbs gradually over this at Long Ashes, then descends quickly down the other side as a noticeable hill. At the bottom of this hill and round a bend is a roadside quarry on the west side. Here can be seen inclined limestone beds with some 7 beds exposed, each 1-2m thick and showing a dip of 18°. (098° 18°S). The limestone appears to be dark grey at first sight, but closer examination shows it as medium to light grey. The dark colour is due to surface staining. Traces of yellow sandstone are present.

A short way farther on the road on its east side, a large drain pipe runs under the road. This is Robin Hood's Penny Well and is the entrance to a cave. In my youth I crawled into this pipe to see what this cave was like. The pipe runs the full width of the road and where it ends there is, or there was, a small crevice out of which a stream poured. It was obvious that further progress would involve crawling through mud and water so I did not bother going any further. I have read since that the cave consists of a long crawl through mud and water! I do not recommend you to explore it.

Let us return now to the walk from where I digressed. We are now on the east bank at the upriver end of Grass Wood, well beyond Ghaistrill's Strid. There is a prominent pebble island in the river and there are extensive pebble beaches.

I now made a diversion and climbed up through Grass Wood on the top side of the road and up onto the open hillside where the Dalesway footpath crosses a tributary valley. Here there are prominent limestone pavements and outcrops to negotiate. There are two shallow valleys making a V shape between them so make your way into one then follow the path round the top of the next. (see Figure 14). A large platform is formed by the fork in the valley floor. The sides of this platform consist of shattered limestone blocks, several inches in size, rather than breccia and the limestone on the north side has a pronounced dip of some 10-20° compared with the general trend of nearly horizontal. There is evidently a fault running down the valley and probably a V split of the fault is responsible for the level platform. The stream running down this valley runs into the Wharfe a little farther upstream of the pebble island. Incidently, Robin Hood's Penny Well is more or less in line with this fault valley.

To finish, we must not miss a trip to Kilnsey Crag. The first exercise at Kilnsey Crag is to try to throw a stone from the road to the bottom of the crag. I always fail miserably, in fact I am of the opinion that it is impossible. The next is to study the structure of

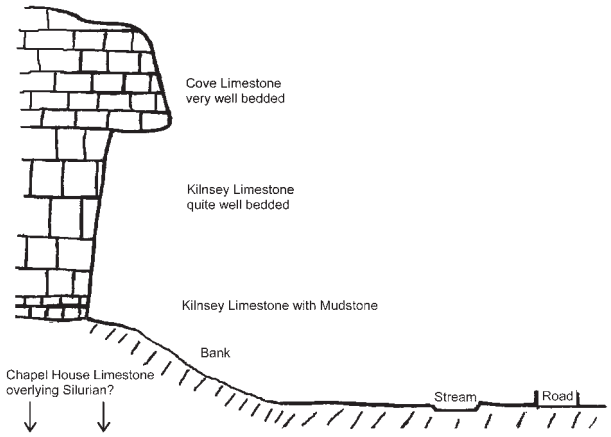

Figure 15. Sketch of section through Kilnsey Crag.

the crag, its height, its large overhang, its flat planed face below the overhang and the springs and small cave at its northern end.

The springs are quite copious and in wet weather water runs out of the cave. Also on the one occasion I crawled in, I am sure I heard water running somewhere ahead but the cave was too low for my liking.

The limestone making up the crag is of three zones (Figure 15). The overhang is Cove Limestone (comparable with the bulk of Malham Cove). The flat face is Kilnsey Limestone and the bottom, just exposed at ground level, is Kilnsey limestone-with mudstone. Below this but not exposed is the Chapel House Limestone. I mention this because the Chapel House Limestone is the one immediately above the unconformable Silurian rocks. In other words the cave possibly lies near the junction of the unconformity - and so does the White Scar Cave at Ingleton - have we got a repeat here? It is food for thought but, according to cave literature, although much squeezing through and chipping of rock has been tried, no large cave system has yet been entered. Still, one never knows. The main drawback to the idea is that the cave does not seem to lie on a line of fault.

My two last trains of thought are concerning the lack of Silurian outcrops in Wharfedale. In Ribblesdale they outcrop up to O.D.250-300m, at Malham Tarn 360m, in Wharfedale there is no sign of them even at 186m. They must be very near the surface. The other is concerning the undercutting of the crag. It is obviously the result of glacial action and I suggest if a glacier came down Littondale the Wharfedale glacier would force it against the valley side where the crag is - the crag is just in the right position.

Before leaving this part of Wharfedale let us cross the valley from Kilnsey to the hamlet of Conistone on the other side and take a walk up the hillside to the high level valley of Mossdale.

Mossdale

Map Reference for start of walk SD982675

One of the striking things about Wharfedale in the region of Kilnsey is the limestone making up the sides of the valley, particularly its north-eastern side. Here can be seen tier upon tier of almost horizontal scars. Take a careful look at these and try to estimate how many you can see and roughly at what height each lies. The reason for this is because our walk passes through the whole sequence and a number of these scars will be recognised (Figure 16).

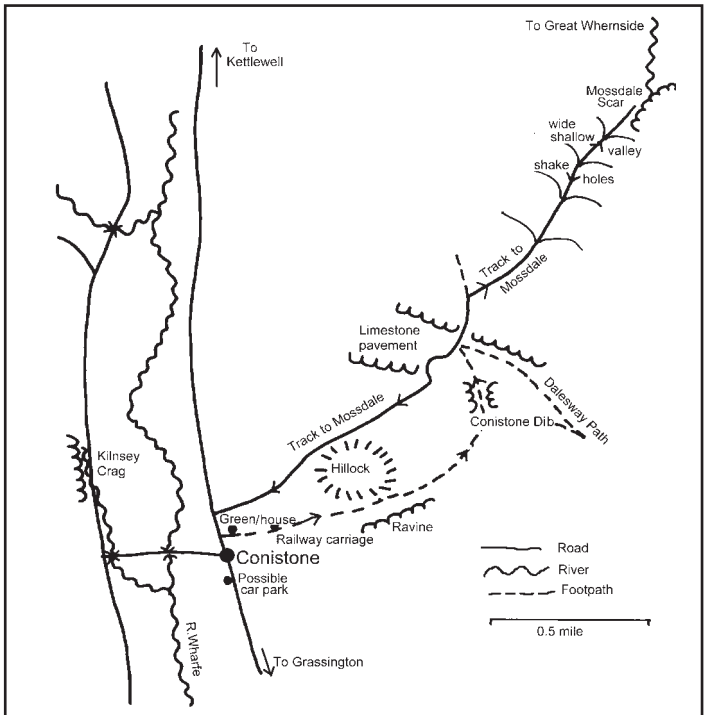

Figure 16. Map of walk from Conistone to Mossdale.

There is the small hamlet of Conistone on the opposite side of the valley to Kilnsey and this is where we can, with luck, park our cars. There is a small patch of wide verge opposite the village hostel/chapel but only a few (~3) cars can be fitted on to it.

There is an interesting scramble up a dry ghyll, rather than using the long drag up the track to Mossdale. At the road junction walk along the road towards Kettlewell but in only a matter of metres turn right across what looks like a small village green and aim for the right hand side of the house on the far side of this green. There is a gate and a sign pointing to Conistone Dib. Follow this sign and you will find yourself walking up a narrow, dry valley past an old railway carriage.

The first feature is the limestone outcrop straddling the valley, making a large step or dry waterfall. I found a few crinoid fossils here. There is a prominent bedding plane and erosion surface, one of many we shall see on our walk. The limestone shows shallow water type structure, suggesting the limestone was deposited in a high wave energy regime.

We are now at the start of our ravine and you will notice that the walls have become vertical and closing in to no more than three feet or so apart. The ravine takes on a twisting course. Just before, and at, the twists have a careful look at the walls, particularly the eastern wall. Here the dip seems to have changed from nearly horizontal to about 30° dipping in an up-valley direction. The jointing is very pronounced and can be confused with the bedding; at one place in the twists there is a section where the beds look vertical - or is this really the jointing? The beds are massive and dark grey in colour. On the west side, farther up the ravine, the beds are dipping at about 20° with overlying beds almost horizontal. There are good examples of water erosion effects.

You will see from my somewhat garbled description that I found the beds difficult to interpret and my eventual conclusion was that they represent a fault system. This was further confirmed on the

return journey where, instead of coming down the gorge, I followed the track down to Conistone. The track runs along the top of the northwest wall of the gorge and it can be seen that there is a small hillock at this part of the gorge, suggesting that a small fault runs across the gorge here. I suspect there are two faults, one running up the gorge making the course of the Dib valley, and a branch running from the main fault creating the hillock. I shall have to make my usual return visit to look at the ravine more carefully. I find that after a geology walk I tend to mull over what I have (or have not) seen and think of features which need more detailed study - hence my customary later return to the sites.

The gorge now widens slightly and takes on a v shape with large limestone screes extending from the foot of the vertical cliffs above down to the middle of the valley.

Here I found among the scree debris, fossils of corals, probably *Dibunophylum*. The scree rock had an oolitic texture but also contained small fragments. I would call this an oolitic limestone.

The path next divides, one branch climbing over a stile and running east towards Grassington, but our path continues up the valley which veers slightly left and heads towards a second gorge, namely Dib Scar itself. The path runs up the middle of the valley and accompanies a wall which is on the left hand side of the path (Figure 17).

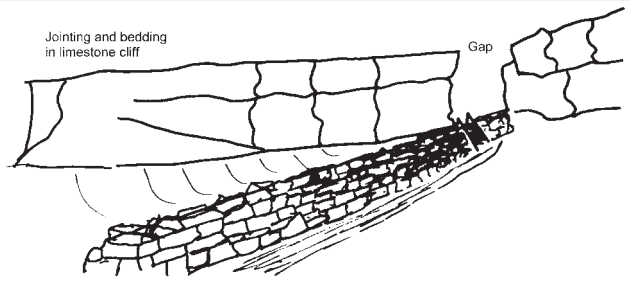

Figure 17. Gap and Scar at the top of Conistone Dib.

As one enters the next ravine one hears a rumbling sound which comes from a large, green plastic object over the wall. There is the sound of running water so this may be connected with a water supply to the village, or a local farm. A few metres up valley of the green object, water can be seen to emerge from the rocks in the valley floor and immediately sink again. Near here I found two large stones or small boulders, which were whiter than the surrounding rocks and had a distinct green hue to them. The hue was not due to lichen but was part of the rock itself - copper contamination? Here the screes are missing and the valley walls are vertical, light grey limestone cliffs. The valley closes in until we are confronted by a limestone cliff across our path. It is not very high and easy to climb, but, before climbing through it, have a study of the northern wall and note the bedding and jointing of the rocks. I have tried to make a sketch of them. The beds have an apparent dip of about 20°, hence more evidence of the presence of a fault running up the ravine. (I only measured the dip from the face, i.e a two dimensional view instead of three, hence the "apparent" dip rather than "true" dip).

The path climbs out of the gorge to meet the Dales Way footpath. Here, turn left (north) and join the main track which leads upwards and over the hill to Mossdale. Note the limestone scars in front of us are almost horizontal.

We have climbed through at least three of the scars mentioned at the beginning of the walk when we first looked at the side of the Wharfe valley. The first scar was at the entrance to our ravine, the second scar we have just climbed through and the third one is the one on the top side of the Dales Way.

Our track now climbs through, or more accurately round and through, this scar which will be seen to be crowned by a large, prominent limestone pavement, giving good examples of clints and grykes. Let us look more carefully at this pavement.

The pavements seen at Moughton and, to some extent those on the top of Malham Cove, tend to break into large flaky slabs some of which wobble, but these we are on here have a blocky, non-wobbly shape but are really hazardous to walk on. The limestone must have a different texture, probably more thickly bedded and may represent deeper, calmer water conditions for deposition than those associated with the Moughton deposits. Also there is a well preserved lime kiln nearby with a low limestone scar behind it. Note also a large pond on the level ground beyond the pavement. Is this a form of dew pond?

The limestone now takes on a darker, coarser, muddier appearance as the track curves round yet another scar. There are lumps of sandstone in the track but they could have been introduced when the track was repaired rather than being the local country rock. The track eventually passes through a gate and makes a gentle descent into Mossdale.

The Mossdale valley is wide and shallow and its floor covered with reeds. Its nature is more of a sandstone/shale vegetation rather than limestone, but there are limestone scars higher up on the valley sides. There are numerous shake holes alongside the path which suggests limestone beneath. The nature of the valley is at first sight rather perplexing until we remember we have climbed through the Great Scar Limestone and should now be on the overlying Wensleydale series with their alternating strata of sandstones, shales and limestones.

Note the limestone scar on the easterly side and follow it up valley. The path does this for us and eventually reaches a large limestone cliff into which a wide stream runs and goes underground. This is the entrance to Mossdale Cavern. Do not expect a spectacular entrance. The true entrance is not where the bulk of the stream enters the cliff face, but several metres to the left (i.e. facing the cliff) where a memorial plaque relating to a tragic accident is fastened to the scar. The cave system is not easy to enter, particularly since it was blocked. It looks as if there are other entrances along the base of the scar but they would be very difficult to penetrate.

The scar itself is rather heavily stained limestone and horizontally bedded with prominent vertical jointing. The beds are about 1.5m thick at the bottom part of the cliff becoming ~1m thick at the top. There is a belt, about 0.5m wide, rich in large *Productus* shells along the base of the cliff. The shells are in "life" orientation - see my attempt to draw these (Figure 18).

Figure 18. Distribution of *Productus* shells at the base of Mossdale Scar.

Figure 19. Kilnsey Crag.

Where the stream runs into the cliff there are the remains of a fairly recent rock fall. The fresh rock is a light, grey, crystalline sparite with crystals up to a few millimetres across (a wackestone?). The limestone is also crinoidal, the ossicles present being very small.

In contrast to the limestones we saw which showed shallow water features, such as sand waves and erosion surfaces, this limestone has the characteristics of a deeper, quieter depositional environment with a more uniform bed form, little or no high energy characteristics and brachiopods in undisturbed positions.

There are impressive examples in the stream bed of water erosion, similar to those found deep within caves, and deposits of fine sand at the foot of the cliff. The stream is flowing over gritstones and from here to the top of Great Whernside the rocks are sandstones and shales. We are thus at the top of the limestones of the Wensleydale series so, I conclude, the Mossdale limestone cliff represents the Wensleydale Main Limestone band.

Make the return journey by the track rather than the ghyll. The reason, apart from being easier at the end of a walk, is to be able to see the relationship between the hillside and the ghyll, particularly at the lower ravine. The small hillock mentioned earlier can be seen and a concept of possible faulting better observed.

Finally on the last stage of the descent look across the valley to Kilnsey Crag (Figure 19). Note the vertical gash through and above the middle of the crag and also the dark band running along the base of the cliff; these can be seen better from here than at the crag itself. However, from this position the crag's overhang is not obvious. The three types of limestone making up the crag can be easily picked out, namely Malham Cove Limestones, Kilnsey Limestones and Kilnsey Limestone with Mudstone.

Our track joins the motor road near the village, so turn left and in not many metres the hamlet and car parking spot will be found.

Sequence of limestone associated with Kilnsey Crag:

Gordale Scar Limestone	Not seen in the crag but situated well above the top making up the higher ground
Cove Limestone	The limestone above the overhang
Kilnsey Limestone	The bulk of the rock below the overhang
Kilnsey Limestone with Mudstone	The lowest beds just visible at the foot of the crag.
Chapel House Limestone	not visible
Silurian rocks	Not visible but according to the rock sequences should be close to the level of the valley floor

Author

After National Service in the RAF as a Radar Technician, Alan Stollery gained a London University External BSc in Chemistry and Physics. He spent 10 years in the textile industry before entering teaching. Alan was the teacher in charge of Physics at a Halifax Grammar School. After taking early retirement he took up geology as a serious hobby and gained a BA (Open) degree. The ramblings are made up from detailed notes whilst walking around the countryside.

Book review

Geology of the Hamilton District by I B Paterson *et al.*, 1998, BGS, 289pp, £35.00 (paperback) ISBN 0118845330.

If you are wondering what to buy a geologist for Christmas, birthday or at any other time; if you are visiting or leading a field trip to the Hamilton district; if you are an armchair geologist or a geology student, then I recommend a copy of the British Geological Survey memoir on the Geology of the Hamilton district. This (soft-cover) book provides a detailed description of the geology written in simple, straightforward terms. The book is illustrated with a wealth of diagrams, maps, charts, cross-sections and photographs. The authors guide the reader through each period of geological history. There is also a section on geophysics and one on economic geology. There is something for everyone. At £35 it is good value and one of those books you will want to have in your library.

Ron Whitfield

Field trip to Gibraltar: 26 - 30 April 1999

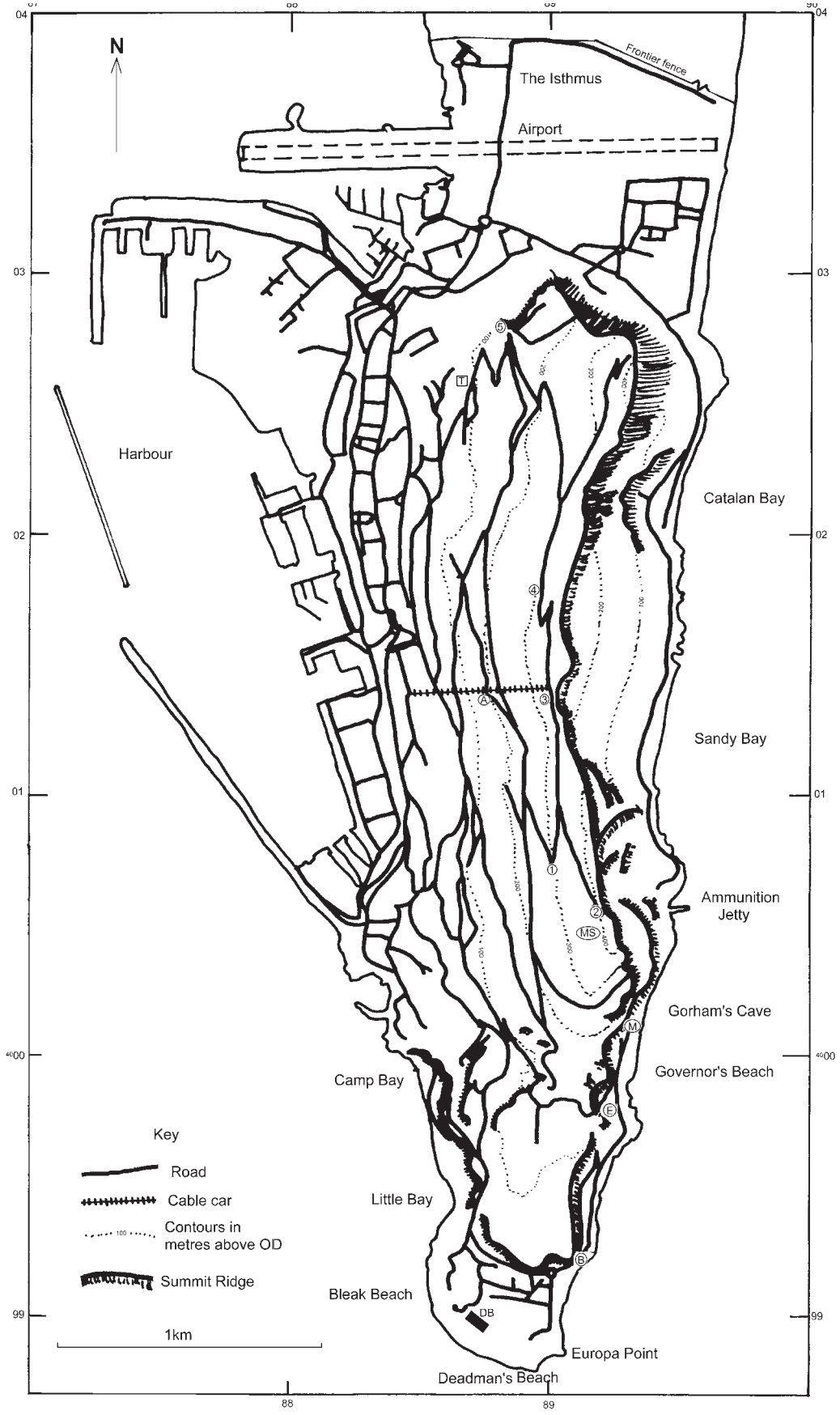

Figure 1. Map of Gibraltar showing contours, roads, the Summit Ridge and venues visited. After Rosenbaum & Rose (1991) and Rose & Rosenbaum (1991).

Participants, with contributions from those marked *:
Rowena Allsopp*, Mary Belcher, Jenny Bennett*, Jane Clarke, Trevor Clarke, Edward Forrest, Jenny Forrest, Dilys Hand, Frances Isaac*, Susan Larkin, David Maddocks*, Elizabeth Maddocks, John Mather, Helen O'Neill, Patricia Osborn*, Jackie Phippard*, Sybil Richardson, John Stanbridge, Penny Stanbridge, Geoff Truss, Irvine Walker, Arthur Whitehouse, Bill Willows.

Walton Hall Branch organised a field trip to Gibraltar on 26-30 April 1999, led by Dr Edward P F Rose. Whilst Gibraltar has a land area of only 5.8km^2 its strategic and military importance for the last 800 years or so have been out of all proportion to its size (Figure 1). With some 50km of tunnels through `the Rock`, almost all of military origin, it is to be expected that most geological research has been undertaken by the military. Dr Rose has been the Senior Geologist in the Territorial Army (from 1974 to 1990), and was Commander of the Royal Engineers Specialist and Specialist Advisory Teams (V) from 1974 to 1990, so he was particularly well placed to lead what turned out to be an unusual and very enjoyable field trip. He is currently a Senior Lecturer in Geology at Royal Holloway, University of London.

The programme provided for three full days of geology so after a short flight from Luton and a pleasantly warm evening walk in the docks area setting the geological scene it was heads down for some interesting field visits.

27 April - The southern plateaux of the rock

1st Locality: Camp Bay

We started our first day with some engineering geology at the southern end of the Rock looking at stabilisation work north of the outlet from the military desalination plant (called the 'Glen Rocky Distillery'!). In view of the changes in the political situation over the years, Gibraltar does not rely on water from mainland Spain, but desalinates seawater for both military and civilian use. Later in the trip we saw older methods of collecting rainwater to maintain an independent supply.

The Great Main Fault, which divides Gibraltar in two, is close to Camp Bay; this has resulted in highly tectonised Mesozoic bed rock which is fractured and unstable. The 'shales' at the base are purply mudstones with cherts. The cherts have not been dated - they may or may not be the same age as similar sequences on the other side of the Rock; there is no proof that they are the same, although they look very similar. Competent limestones overlie shales. The whole sequence has been eroded and shows evidence of changing Quaternary sea-levels. Rock scree has been removed from here to provide fill elsewhere, with the effect of removing support for the cliffs. There was a major fall during the winter of 96/97 - the wettest winter in recent history on Gibraltar - 800mm of rain, 600mm of which fell in December 96. A large boulder fell and destroyed some of the amenity area, and a short tunnel failed! Stewart Lightbody of Golder Associates showed us the work being done to reprofile the back of the landslip, blasting to form a clean surface in order to make it easy to stabilise. 200-400mm blocks have been used to create an artificial scree slope and to backfill the old tunnel. Some Quaternary breccia here is marine, evidenced by shell debris and borings. The 'shales' are sheared and highly distorted. These mudrocks with cherts have no radiolaria content at this locality. It is not clear whether the cherts in these tectonised rocks are primary or secondary and, sadly, completion of the engineering works may well cover the shales.

2nd Locality: Little Bay

Here we saw the oldest bedrock, the Little Bay Shale Formation. This is formed of dolomite and clastics and dips into the cliff. It has not been firmly dated; there are different interpretations depending on the author's opinion of whether or not the sequence has been overturned. Is it the right way up? There is a quarry across the bay, at Algeciras, which has a similar outcrop containing plant spores of Triassic age and across the Strait there is a comparable Triassic sequence at Gebel Musa. These shales have no cherts, so they may or may not be of the same age. No fossil evidence has been found in the Little Bay shales. We found some loading structures and fining upwards sequences, and so were confident that these in Little Bay were the right way up.

We walked through the Keightley Way Tunnel, taking a look at the engineering on the way. There are rock bolts up the cliff by the entrance, and a concrete portal to minimise rockfall damage. This road tunnel was temporarily closed some 25 years ago when some of the original charges were found in there! Ted told us that he had surveyed the tunnel at that time and amused us with tales of the rather different approaches to engineering that can be taken when there is plenty of manpower! Some remedial work to the tunnel has been carried out and the group walked through it.

3rd Locality: Harding's Battery Observation Post (near Europa Point)

Figure 2. North Africa across the Strait of Gibraltar.

From here we could see Africa very clearly across the Strait (Figure 2), with Gebel Musa, the other Pillar of Hercules, about 14 miles away - the Strait is much narrower than the English Channel at Dover! After we had observed the 'Last shop in Europe' with 'Much Cheapness' and the new mosque which has been built on the Europa Flats, we looked northwards back at the Rock. There is a series of platforms here; the lower one, the Europa Flats, is thought to be a Quaternary wave-cut platform backed by cliffs. Above this large platform are the Windmill Hill Flats thought to be another wave-cut platform. Europa Flats are 30-40m above sea level, and Windmill Hill 90-130m. They have different slopes, but the overall slope is to the south; perhaps the differences are due to tilting? Ted discussed these aspects and suggested that the two Pillars of Hercules could be part of a single nappe but that subsequently Gebel Musa and Gibraltar had been fractured and rotated by different amounts.

4th Locality: Bleak Beach

We made our way to this beach of rubbly boulders, stopping to admire the wonderful flowers. The rocks were dolomitic limestones of the lowest (Bleak) member of the Gibraltar Limestone

Formation, showing cryptalgal laminae. These are produced by sediment building microbes in shallow water conditions. Interestingly, these sequences are 400-600m thick; this means that there must either have been sea level rise or subsidence to allow these thick sequences to form. The rocks have been dated as Early Jurassic from the brachiopods found, and this is consistent with dates that Dan Bosence (Royal Holloway) found by Sr isotope work on the shells.

There is no evidence for major sea level rise here in the early Jurassic - so it is suggested that this could be regional subsidence. The dolomitisation seems to be of a primary limestone - thin section work has shown that apparently the dolomite overprints the calcite. The dolomite here is relatively dark-grey with a dip to the east.

An overlying Quaternary breccia here is subaerial in origin but as we walked round past an outflow pipe we found many marine mollusc borings on its surface - more sea level changes? The breccia could have formed first terrestrially, followed by a rise in sea level; then the sediments were intensively bored. These sediments are 9m above the present sea level and, to complicate matters, there is a very hard red deposit which has filled fissures. It is very red and has many mammal bones in it; the suggestion is that these have been washed or blown in later, possibly as a cave deposit.

5th Locality: Defensible Barracks (DB on map)
More dolomites can be seen past the Defensible Barracks. The Keightley Member is seen beneath the Europa Battery. Stylolites are present, so the rock must have been subject to pressure solution, the rock shows light/dark alternate areas, and has an apparent dip eastwards.

6th Locality: Deadman's Beach
The rock here has been eroded to form a narrow new horizontal platform, more mollusc borings are present and, further round, there is another raised beach with sand and pebbles. More of the red material seen at Bleak Beach is found here as fissure infill, full of vertebrate bone fragments. The Hunter brothers (for whom the Hunterian Museum in Glasgow is named) spent time looking at such material. On walking further round the bay, there was clear evidence of faulting - large areas of slickensides could be seen by the sea.

7th Locality: Beefsteak Cave
Named for a barbecue locality! Up the cliffs behind the mosque, just below Jacob's Ladder, we saw the faulted Keightley Member. There is also a fossil bed with algal laminae and disarticulated brachiopods. We convinced ourselves that these were the right way up.

8th Locality: Buffadero (B on map)
Further up through a little tunnel, there is a more uniform looking limestone, NOT dolomite (Buffadero Member). It is fossiliferous and the shell content suggests a more open marine environment. The rock has a uniform pelleted appearance, and appears crystalline. Ted showed us an interesting series of holes within overlying Quaternary breccia which had apparently been made by bees - this means that there must have been flowering plants present, which gives a range of possible temperatures. These burrows are also evidence for soil formation - bees burrow into soft stable material to form burrows which then fill up with calcite. The breccia here is very angular with a large range of sizes - this suggests a more extreme climate, possibly with frosts?

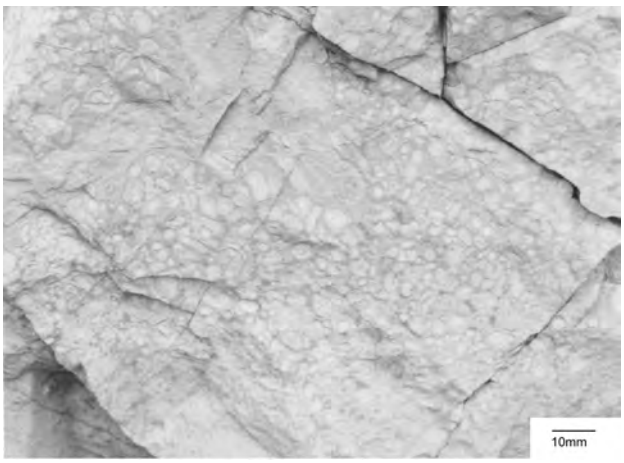

Figure 3. Oncoids

9th Locality: Europa New Road
Returning to the road we saw Buffadero limestone with rip-up clasts in algal mats and oncoids - small concentric chemical concretions (Figure 3).

10th Locality: Europa Advance quarry (E on map)
We stopped to look into this small quarry up the hill which provided sandstone for gun embrasures. The sandstone is Quaternary; it is very shelly, very coarse, loosely cemented, marine derived - possibly from a beach environment. Terrestrial gastropods have also been identified.

11th Locality: Hole-in-the-Wall Road
Walking up this military road it is possible to see another conglomerate with very rounded pebbles indicating a water-lain deposit. This Quaternary sequence is some 80m above present sea-level.

12th Locality: Monkey's cave (M on map)
This is near the top of the steps to Governor's Beach, along a military road; there is a section here with Quaternary cross-bedded units and another raised beach. It is a long way up, 55m above present sea level. This cannot be due to just eustatic change, it's too great a rise, so it is thought to be tectonic.

Here we met Clive Finlayson from the Gibraltar Museum who took us to Governor's Beach to see the caves.

13th Locality: Governor's Beach
After climbing down the long flight of steps, we made our way to Gorham's cave. This site is important for the remains of Neanderthal man and other cave users found here. Remains of stalagmites are also present. Inside there are beach sands stuck to the edge of the cave and loose sand on the floor. The cave was discovered in 1907 when the deposits filled the cave to the entrance. Captain Alexander looked at it in 1940. Ceramics were found, including some Punic and Phoenician fragments. The lberian peninsula is important as it was a late refuge for Neanderthals. Later there was a shrine here which accounts for many of the Roman artifacts. It is thought that sailors made offerings before going through the straits. Oxygen isotope studies show evidence of temperature changes but the savannah-type vegetation would not have changed. However, the marine fauna does change dramatically with temperature and this is reflected in fossils found in the caves. Unfortunately Gorham's cave was excavated later, and

Figure 4. Vanguard Cave

much of where we stood is excavated spoil - known as 'Waechter's spoil' after the man who was responsible! Obviously a great deal was missed so, from the end of the 80s, when Chris Stringer from the Natural History Museum restarted work here and on Vanguard cave, very different methods were used. High-resolution stratigraphy is now used and every artifact is logged according to its 3D position in the cave.

Vanguard Cave (Figure 4) lies immediately northward of Gorham's and its sediments are undisturbed. Sandbags have been used to hold the excavated sequences in position; they consist of very thick deposits of sand. The oldest so far is on the limit of carbon dating. There is some evidence of human occupation - probably Neanderthal. There is evidence of flint working, one core, two blades and some human coprolites which are being tested for DNA. Beyond 44,000 years there is no human occupation but there are signs of hyena. The caves would have looked out over a vast savannah area, rich in animals for hunting, which is thought to be why they were a refuge for the Neanderthals.

Figure 5. *Macaca sylvanus.*

In the evening we were fortunate to have a lecture from Clive Finlayson on the Quaternary on Gibraltar, where we heard more about the finds on the Rock, and the changes over its recent geological history.

28 April - Main Ridge of the Rock

The main ridge area of Gibraltar is formed of massively bedded limestones. It extends from the North face southwards for approximately 2.5km, the sharply ridged crest rising to a maximum height of 424m above sea-level. The limestone dips westward with a relatively gentle slope towards the town and harbour and with a steep scarp slope to the eastern coast.

The group ascended the main ridge from the town via the Cable Car as far as the lower terminal then walked by road uphill to the Apes' Den (A on map). The primates, centred upon the den, are properly called Barbary Macaques, *Macaca sylvanus* (Figure 5), and probably originated from escaped pets brought over by British troops in the 1700s. They later acquired the symbolism associated with them of British sovereignty i.e. if the 'apes' leave Gibraltar so will the British. Huge iron rings bolted at intervals in the rock bordering the road were once used to haul heavy cannon. An example of a fougasse or rock mortar, dated 1771, was examined. Hollowed out of the limestone, it was abandoned shortly after as its delivery of shot had so short a range it fell within the fortress (Figure 6).

CUT INTO SOLID ROCK IN 1771
HEALY'S MORTAR WAS INTENDED TO HURL
OVER A THOUSAND STONES WEIGHING OVER
11b EACH ON TO ANY ATTACKING FORCES,
BUT IT PROVED UNSUCCESSFUL AS MOST
STONES FELL INSIDE THE FORTRESS.

Figure 6. Rock mortar ~1m diameter.

Passing through the Queen's Gate of Charles V's defensive wall the group turned southward towards Old St Michael's Cave (1 on map, Figure 7). The earliest mention of this cave system is that of Pomponius Mela in 45AD. Its series of chambers containing stalactite and stalagmite formations follow the rock's bedding plane. The cave is easily accessible and is open to the public; one chamber is furnished as a concert hall. There is no marked throughput of ground water and no further cave changes by solution or precipitation. Flowstones and fissure breccias were observed outside the cave entrance. In 1942 a tunnel driven into the largest chamber broke into a series of lower caves which are now called the New (or Lower) St Michael's caves. This system, which contains a 6m deep lake, is not open to the general public.

Figure 7. Old St Michael's Cave concert hall.

After examining a natural heritage display within the cave the group walked northward along St Michael's Road. Well-formed stylolites and algal laminations were examined in weathered eastern faces of limestone bordering the road. The group walked for some 200m before joining the O'Hara Road in a SE direction. The road is cut through the Buffadero Member of the Gibraltar Limestone Formation and leads towards the high point batteries (2 on map). The end of the road leads to a track at the top of the Mediterranean steps (MS on map, Figure 8). Beneath the area of the batteries the steep westward dip of the limestone was clearly visible as was the naturally defensive eastern side of the Rock. The steps which zig-zag down the slope eastward from Lord Airey's Battery are very steep. They were overgrown by shrubs and in places hazardous. The precipitous steps concentrated the mind upon survival and the spectacular views of the east coast, the water-catchment area above Sandy Bay and the Spanish coast were only glimpsed during judicious pauses. A number of plants demanded attention, some for their attractiveness, others for attaching themselves to clothing and skin. The Gibraltar candytuft, *Iberis gibraltarica*, with lilac and pink florets, which grows nowhere else in Europe, was one of the former and *Asparagus horridus* with stiff spreading branches and sharp pointed spines was an example of the latter.

Figure 8. Mediterranean Steps.

Heavy rain forced the group to shelter in Goat's Hair Twin Caves where we were conveniently able to examine a Quaternary raised beach, some 200m above present sea level, the result of considerable tectonic uplift.

Limestone in this vicinity showed evidence for stratigraphic inversion. Empty invertebrate shells acquire a geopetal infill when accumulation of fine mud particles collect at their base before the upper area becomes infilled with sparry calcite (Figure 9a). These and algal features clearly indicated the original deposition orientation.

Many of the distinctive horizons within the Gibraltar Limestone, especially algal horizons, show evidence of rip-up clasts where storms or strong tidal currents 'rip up' fragments from the surface after formation (Figure 9b). These horizons have the clasts of the same material scattered on top. The relationship between clasts and the original horizon is thus able to be used to determine 'way up'. Numerous examples of inversion of the rock were examined.

Heavy rain fell as the group returned by the steep Martin's Path to Old St Michael's Cave area for lunch. Fortunately better weather which followed allowed close examination of bedding plane surfaces of limestone bordering St Michael's Road en route to St Michael's gate (3 on map). Especially good cross-sections of fossil invertebrates, chiefly bivalve and gastropod molluscs, showed more evidence of inversion of the limestone.

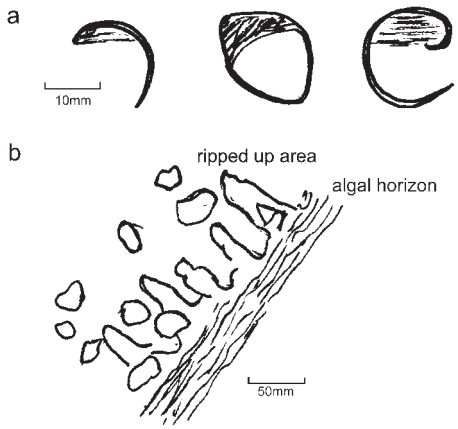

Figure 9. Evidence of inversion; inverted shells seen in the limestone. a) Geopetal infills now at the top of the shell cavity b) Originally the algal band was horizontally deposited above the band of rip-up clasts.

Continuing northward, passing the upper terminal of the Cable Car, the group reached Signal Station Road (4 on map) where layers of ooids were noted in rock faces. Ooids are concentrically layered algal spheroids. They were well-formed, <2 mm diameter and are indices of open marine conditions. Bottom currents had gently rolled the spheres on the sea floor giving time for all-round algal growth.

A relatively easy walk of some 700m downhill from Signal Station Road led to Princess Caroline Battery which was re-built in 1905 (5 on map). The view-point, enlivened by 'apes', was a good stopping place to look northward to Spain across the flat isthmus formed by Quaternary sands. The isthmus is now surfaced by the airfield.

Within the North Face of Gibraltar there are extensive 18th century military fortification tunnels which the group visited. The hard and durable Gibraltar Limestone has been tunnelled since 1782; the last tunnels were made in 1968. A total of 50km of tunnels and chambers now honeycomb the Rock. During the Great Siege, 1779-1783, an attempt to mount guns to bring flanking fire on the enemy resulted in tunnelling behind the North Face by Sergeant Major Ince and the Company of Soldier Artificers. These tunnels, open to the public, exhibit early tunnelling methods using chisels and crowbars which caused minimal damage to the surrounding rock and, as a result, show smooth surfaces and great stability.

Descending towards the town a visit was made to the remains of a Moorish fortification (Moorish Period 711-1462) called the Tower of Homage (T on map). A splinter group also visited the small Trafalgar cemetery. Following the battle of Trafalgar the *Victory*, carrying home Admiral Nelson's body, put wounded seamen ashore at Gibraltar, some of whom died and were buried in this graveyard. They lie beneath the introduced narcotic shrub *Datura* whose large pendulous white trumpet flowers were in full bloom. Traditionally all who sleep beneath the flowers never wake so they were carefully avoided by the group in order to remain alert for the next day's programme to the east coast and Inner Rock.

29 April (am) - East coast

The prospect of a morning spent gently ambling north along Gibraltar's east coast road enthused our group as we erupted from the minibus at the northern end of the Dudley Ward Way tunnel. The squally rain having put paid to any ideas of sunbathing, our minds were free to concentrate on the geology.

Figure 10. Catalan Bay Formation overlain unconformably by ancient scree breccia.

From our first view point, on the steep cliffs above the old ammunition jetty, we observed how the sea was undercutting the inverted Gibraltar Limestone (Lower Lias) and eroding the softer, younger (Middle Lias) 'shales' below. These 'shales' consist of red fissile mudstones interspersed with thinly bedded, cherty limestones which have been faulted and deformed by pre-consolidation slumping and/or subsequent tectonic events. They form the youngest exposed bedrock unit on Gibraltar.

At the southern end of Sandy Bay we had a closer encounter with this Catalan Bay Shale Formation. Here it is overlain unconformably by ancient scree breccia and the Shale's steep southwest dip is apparent (Figure 10). Clustered on the rocks (for it had transiently stopped raining) we posed for photos whilst discussing the formation environment of the shales and the not inconsiderable risk of tunnelling through them (it has been done!), the uplift of the western Mediterranean and the need to increase our serum caffeine.

Dominated to the west by the steep scarp face of the Gibraltar Limestone, the Sir Herbert Miles Road traverses the base of a cryoclastic, boulder breccia scree slope overlain and interbedded with aeolianites. Somewhat unwisely, some may say, the base of this has been quarried at the north and south ends to provide land infill and building material. Between Sandy and Catalan Bays we walked below the disused water catchments, which cover most of the slope. Reclamation and stabilisation of this area is a cause of some concern to the Gibraltarian authorities and the owners of the holiday properties built on the shore below.

Mildly reassured by the presence of anti-submarine netting deployed to restrain falling boulders, iron sheets and over-enthusiastic geologists, our party proceeded north. The more intrepid of the group ventured over a retaining wall to gather samples of the buff coloured Catalan Sands. Hand lenses were whisked into action, revealing mostly well rounded, well sorted quartz grains with some organics present. Further along, quarrying had uncovered the large scale cross-bedding in these Quaternary aeolian sands; mapping has shown they were blown in from the east, when sea levels were relatively lower than at present (Figure 11). There was also evidence of episodic soil formation and plant growth, indicating relatively

Figure 11. Cross-bedding in the Catalan Sands and rusting quarrying structures at the base of the disused water catchments.

stable environmental conditions from time to time in the recent past.

As we lunched below the Catalan Bay Quarry and its impressive fault (downthrown to the north), the weather brightened and the sun began to shine - typical as our afternoon was to be spent underground.

29 April (pm) - The Inner Rock

It all seemed so reasonable when viewed from the comfort of the bar the previous evening. The programme simply said "enter military tunnel complex via Williams Way". The sun was shining (almost for the first time that week) and any passing stranger would have seen 15 geologists, arrayed in a motley selection of hard hats, boots and sundry rain gear, sunning themselves on the concrete ramp marking the entrance to the tunnel. Our military guides had forgotten the keys! When our caving expert did arrive with the keys it was almost a shame to go in.

Almost the first thing we were told, apart from keep your hard hats on, was that there were over 500 steps to climb before we really entered the tunnel complex. This caused minor muttering and a few sighs but we all made it (for the first time I was really grateful for my hard hat - the roof was very low in places) and were rewarded by spectacular views of the airport, and across the frontier to La Linea, from Jock's Balcony - the military usage of this vantage point being apparent to all. It was tempting to stay sunning ourselves and rest weary limbs but eventually we were persuaded to plunge back into the inky darkness (and it was very dark - the lights had failed in the next part of the section and were not up to much in the core store!). Apparently in the past cores had been drilled to establish the presence of an aquifer under the rock and the best place to store long cores was in the disused accommodation caverns. The cores are no longer intact, having been collected by passing tourists (and geologists).

Concentration now was not really on the geology of the rock, we were here to admire the work of generations of military tunnellers - and boy could they tunnel! The section of tunnel in which we stood was begun during the 19th century and had remained in tranquillity until the 2nd World War when a pressing need for accommodation saw embrasures in Willis, Queens and the Upper Union Galleries becoming barrack rooms. By the end of the War something like 40km of tunnels had been cut in the rock, removing about 1 million cubic metres. The Tunnelling Companies of

Figure 12. The hazards of slope base quarrying are revealed below the fault at the northern end of Catalan Bay.

Royal Engineers used drill and blast techniques cutting 60m of 2.5 x 2.5m tunnel in a week. Unfortunately the fast explosive blasting led to large-scale fragmentation of the tunnel rock. Stress release in these fractures now leads to loose rock that has to be removed occasionally for safety. Initially some chambers had a 35ft span, cut with flat soffits, but this caused problems, with rock falls a frequent hazard. Subsequent chambers having a span greater than 12ft were arched, giving greater stability; there were only a few sections that required steel nets attached to the roof to prevent small falls. Within some of the tunnels Nissan huts had been installed, complete with windows - almost a 'womb with a view!'

We declined the use of some less than salubrious latrines (it was not just the lack of doors that caused our usually pragmatic bunch to move on hastily!). However, we did accept the invitation to scramble over a low wall into an office complex that was installed during the 2nd World War. Unfortunately the lights here did not work either and we had to rely on torches and lamps attached to our cave experts' hard hats. We could however see enough to appreciate the difficulties faced by those who would have worked here during the war; attempts to make things more pleasant included lights placed outside the windows to imitate sunlight. Hopefully this was more effective than our guides' attempted recreation that actually added to the gloom!

It is hard now to remember the sequence of tunnels, it was too dark in many areas to make notes; however, negotiating the blast walls in the smaller tunnels (requiring a certain amount of dex-

terity) highlighted the subsequently roomy areas such as the accommodation area and the Great North Road. Military usage of these tunnels is now reduced, but some sections still serve as munitions stores or as reservoirs. Although the rock is honeycombed with tunnels its overall structural integrity remains. Obviously unfaulted Gibraltar Limestone is the rock for tunnelling!

We exited the tunnels at Maida Vale, emerging mole-like into the strong early evening sun. We had exceeded our guides' expectations and had 45 minutes to wait for our transport on to Lower St Michael's Cave. This gave us an opportunity to resume our sun bathing, again on concrete!

29 April (evening) - Lower St Michael's Cave

Having visited the large, spacious Upper St Michael's Cave the day before and euphoric after surviving the claustrophobia of the military tunnels, I felt I was ready for anything ... to be honest I did not feel anxious about the last visit of the trip and after checking that we did not have to squeeze through small spaces, I braced myself to go underground.

I think that I was not alone in believing that the first rope down would be the last and we would simply walk along in comparative comfort admiring the beauty and drama of stalactites and stalagmites. However, we were in for a shock! Maybe the cave guides' outfits should have given us a clue - WE WERE CAVING. Crouching low through pools, ducking under stalactites, clinging to ropes for dear life as we climbed up and slid down, twisting and turning to find a truly wondrous sight around each corner.

Unfortunately I did not really appreciate the geology, as survival was foremost in my mind, but it certainly was an experience I shall never forget. There may only have been one rock there, i.e. Gibraltar Limestone, but it showed itself in a variety of forms and intricate shapes. I do remember touching one piece of rock which Rowena described as stroking a dinosaur's skin (not sure when she had stroked one before!). It was certainly much drier than it looked and rough. Another formation looked like haematite.

The fast and brave of us went ahead to view the lake - I was not one of those - but I understand it was beautiful and surrounded by a rim of calcite with a serene atmosphere.

If I had known what Lower St Michael's Cave was like before descending the rope I would probably never have gone but, in a bizarre sort of way, I am glad I went. It was an experience I am never likely to repeat!!

References

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Book reviews

The Regional Geochemistry of Northeast England 1996, British Geological Survey 100pp, £50 (hardback) ISBN0852722559.

The first thing that strikes you about this book is its size, but on opening it the reason is evident. The book consists of a series of maps in full colour, giving the concentrations of various chemicals in soils and sediments. The area covered is from Bridlington on the Yorkshire coast to South Shields on the river Tyne and as far west as the Pennines. It covers the classic North Pennine Ore field and the Durham coalfields, both of which have had a major influence on the distribution of the chemical elements of the area.

The introduction is a detailed account of the sample collection and preparation and the methods used to determine the chemical compositions, along with error controls and how the data was interpreted. This gives a good insight of research methods and data presentation and the control of statistics upon them. The following chapter is a very good detailed introduction to the geology of the region from the Carboniferous to the latest superficial deposits. A short discussion of the structures affecting the Carboniferous strata is included.

One of the most interesting chapters for me was the one dealing with the mineralisation of the North Pennine Ore field. The table of mineral deposit locations was especially interesting, as many are well outside the areas of the known ore field. It also deals with mineralisation of the coalfield which gave rise to the iron industry of Conset and the ironstone of Cleveland, which laid the foundations for much of the heavy industry of Teeside.

Each map of element concentrations is accompanied by a text, which gives a description of the element itself and its distribution through the sedimentary strata by geological period. An explanation of the source and any anthropogenic influences it may have is also given.

The information in the book could be used for a variety of environmental applications including the location of toxic levels of chemicals, which may be to the detriment of humans or livestock and crops. The natural levels of the elements are also given so the effect of past, present and future land use can be assessed. The book is ideal for land use and planning issues and may be of assistance in mineral exploration and resource evaluation.

John Burke BSC Hons (Open)

Geology of the Fortrose and eastern Inverness district by T P Fletcher, C A Auton, A J Highton, J W Merritt, S Robertson & K E Rollin, 1996, BGS, 137pp, £50.00 (paperback) ISBN 011884511X

This memoir covers part of the Great Glen and its extension into the Moray Firth. It covers very ancient rocks indeed which have subsequently been deformed and metamorphosed by the Caledonian orogeny including the Rosemarkie Metamorphic Complex and the Central Highland Migmatite Complex. Metamorphic and Igneous rocks have their own chapters as does the later Devonian and the Quaternary, Permian, Triassic and Jurassic rocks share a chapter. Geophysics and Economic geology are also covered.

The familiar formula of double columns, clear printing, well presented diagrams and figures is followed in this volume which retails at £50. It is a great book with a wealth of detail and colour additions to the figures etc. I was glad to see that the black and white photographs were large as well as the thin sections. I think there are rather more pages without illustration though, which might make it harder going for some people. Another book that I would like to have on my shelves, just for the reading matter and knowledge within its pages. There is a magnificent photograph as a frontispiece of Ardersier Peninsula with an explanation of its geology. Figure 29 showing glacially sculptured benches and raised shorelines on the Black Isle certainly made me think it is a place worth visiting some time but only if I can take this book with me.

Appendices are of modal analyses of granitic rocks, geochemical analyses of metamorphic and igneous rocks, Quaternary Sites of international importance, Quaternary fossils beautifully photographed and a list of GS photographs. There are plenty of references and an index.

Doreen Smith BSc and continuing Earth Science student

A tourist's eye view of New Zealand's continental plate margin

Jane & Trevor Clarke

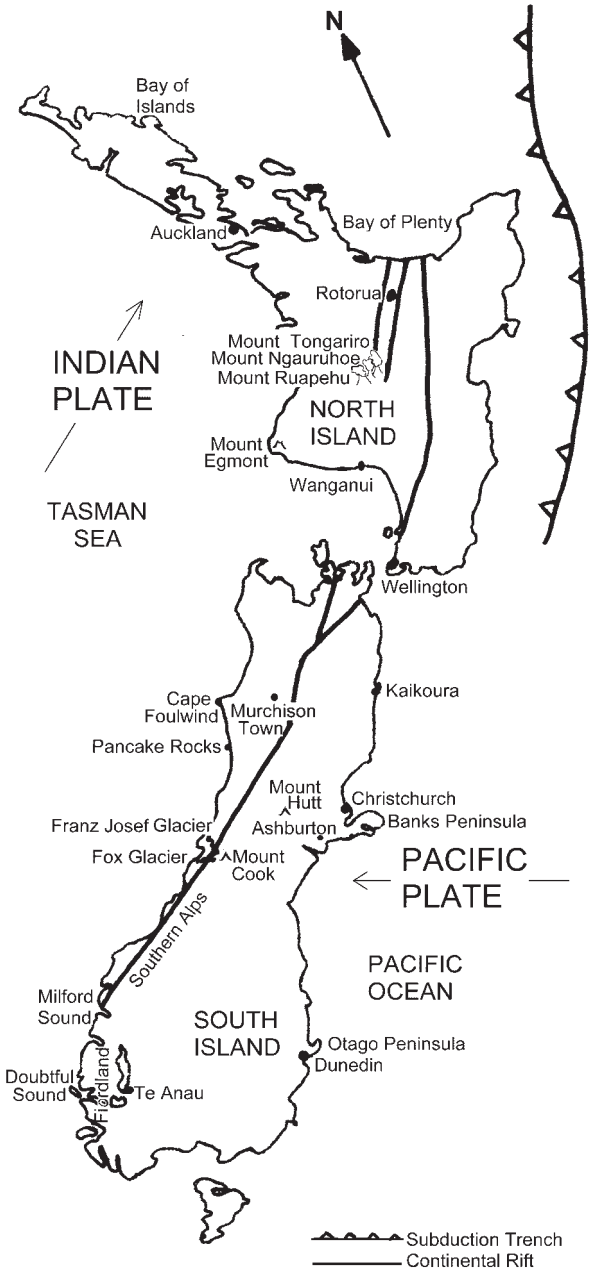

Figure 1. Sketch map of New Zealand to show locations mentioned in the text. Scale 1/10 000 000.

This is an account of a holiday taken by the two of us in New Zealand during January, February and March 1999. Very little geological preparation had been done in England; all we had was a geological map of North Island borrowed from the GA library and a small-scale geological map copied from the World Geological Atlas. We had assumed that informaton would be readily available in New Zealand; how wrong we were! No-one in South Island appeared to have heard of geology and no information was available either in the bookshops or tourist information centres. There was a telephone number on the geological map of North Island which we rang and we were invited to visit the New Zealand Institute of Geology and Nuclear Sciences when we reached North Island. They were most helpful and supplied us with the last copy of their double volume *Geology of New Zealand* complete with maps and a set of their popular A3 fold-out geological information sheets (similar to our BGS Holiday Guides). They do a lot of good work, but seem to be working in a vacuum with no obvious general outlet for their publications. For us it meant that, although there was no geological requirement attached to our holiday, there was a great geological interest and we had to make the best of what observations we could - hence the "tourist's eye view".

New Zealand exists due to the oblique movement of the Indian Plate (they call it the Australia Plate) against the Pacific Plate; in effect the Indian Plate is moving roughly northeastwards and the Pacific Plate roughly westwards (Figure 1). There is an active offshore trench: off the east coast of North Island where the Indian Plate is overriding the Pacific Plate causing volcanism on North Island. The plate margin runs through both islands as a shear zone, causing the uplift of the mountains of the Southern Alps and Fiordland. So the two islands are the result of ocean floor sediments being squeezed upwards to form mountains and eruptions of volcanic rocks due to the subducting oceanic plates.

We flew into Christchurch from Bangkok, collected the camper van which was to be our home for the next 6 weeks, drove to the nearest campsite and spent the next few hours in a jet-lagged sleep. The next day we loaded up with groceries and headed eastwards. Banks Peninsula was formed from two basaltic volcanoes with vents very close together, Lyttelton (10-12Ma) and Akaroa (7.5-9.5Ma). The calderas weathered and sank and the sea flooded in to form what today are Lyttelton and Akaroa Harbours. A boat trip round the harbours shows their origins; the bays are flanked by layer upon layer of basalts, the weathered ash beds in between are now used by seabirds as nesting sites. In a cave on a beach in a Maori reservation, between two layers of basalt, was a layer of red ochre mud with finger marks where it had been scraped away - to be used as body paint?

We returned to Christchurch and then headed southwest over the Upper Quaternary and Recent glacial deposits. The road was dead straight and flat; sometimes you could see for 10km ahead. Cut by the occasional braided river, these sediments are evidence of the extreme amount of glacial, water and frost weathering in the upwardly moving mountains.

By the time we reached Ashburton we were thoroughly fed up with the flat terrain so we turned right and headed northwest towards Mount Hutt. As we approached the Hutt Range the flat sediments were replaced by layered benches showing where previous glacial outwash lakes had deposited their load. There were no foothills as such, the mountains rose sharply from the sediments which covered the mountain roots.

New Zealand is notorious for its rainfall but, while we were there, it was experiencing its longest and hottest heatwave for 150 years with the result that aerial viewing flights over the mountains were not hampered by the weather. We took a helicopter ride around

Figure 2. Fox Glacier. Top: the icefield, icefall and top of the glacier; Middle: the glacier; Bottom: the toe with glacial stream issuing from the ice tunnel.

Mount Cook, which at 3745m is the highest mountain in New Zealand. There was a large avalanche in 1991; the gash is still visible and the snow cornice shows evidence of the high winds which blow over the peaks. We landed in a corrie near the top of an adjacent mountain, disembarked and threw snowballs at each other whilst admiring the view.

Our return flight took us over the top of the Fox and Franz Josef Glaciers, an amazing sight with icefalls producing huge crevasses and valleys gouged out leaving lines of rock debris on the surface. About a week later we walked to the feet of the two glaciers; Fox Glacier (Figure 2) was too dangerous to approach closer than about half a mile, but we stroked the freezing toe of Franz Josef (Figure 3). It is difficult to describe the sense of awe at the size of the glacier when it is approached closely; from a distance it looks

Figure 3. Franz Josef Glacier. Top: the toe of the glacier; Bottom: the face of the toe, Jane lower right for height.

just like ice in a valley, but when you get close it towers above you and creaks with the occasional mini-car-sized chunk falling off the face (and people still walk under overhangs!). The glacier flows downhill at 1.5m per day and there is a constant trickle of sediment from the face to remind you that this huge monster is mobile. It is, of course, melting and the meltwater river gushes out from a huge ice cave from which issue loud thumps as blocks of ice fall from the roof into the sediment-loaded river. The sediment which lines the glacial river channel varies in size from enormous chunks of rock to rock flour and illustrates how the flat sediments we crossed southwest of Christchurch were deposited. The larger boulders bore striations gouged out of their otherwise smooth surfaces.

We made a detour to the coast in order to visit the Moeraki Boulders (Figure 4). Maori legend has it that a great canoe Arai Te Uru was wrecked in a storm and its cargo was washed onto the beach. The boulders are the water gourds and food baskets. Other natural features such as a reef and nearby hills bear names of the crew. The boulders are huge septarian nodules, up to approxi-

Figure 4. The Moeraki Boulders.

mately 2m in diameter, which are weathering out of the cliff. They are concentrated in a small area and are in various stages of disintegration; some are complete while others have broken open to expose the calcite crystals.

Another extinct Miocene volcano forms the Otago Peninsula adjacent to Dunedin (Edinburgh of the South). We found later that the map lists basalt, andesite, trachyte and phonolite in sheets and flows but it rained and blew a gale (the only time we had real rain) so we just admired the view from the van windows without collecting any samples. Similar to the Banks Peninsula the flooded extinct caldera forms Otago Harbour. While in Dunedin we took a train ride into the mountains to Middlemarch; *en route* the guide pointed out a line in the trees and announced that it was THE Continental Plate Margin, no further explanation was given leaving most passengers totally confused. Being as the margin is some 250km to the west we found his facts a bit suspect. However, the scenery was breathtaking with steepsided gorges and a great variety of both tropical and temperate plants. The Edwardian station at Dunedin is well worth a visit, being built of brown sandstone with white facings with a Roman-style mosaic floor made of Royal Doulton chinaware depicting steam engines, carriages, signals and telegraph poles - wonderful.

From Dunedin we travelled west to Lake Te Anau where we were to spend a few days. Lake Te Anau is situated on the east side of what the locals call "Fiordland", a mountainous region virtually inaccessible except to the toughest walker/climber. There are strict rules for those who wish to enter this wilderness - no contamination must be caused, so no fires, no rubbish, no packaged food must be taken in and if the explorer gets into trouble they have to fend for themselves as no helicopters or any other vehicles are allowed to enter. These mountains are composed of Ordovician basic paragneiss and amphiboles and are being uplifted at the rate of about 2cm per year. As the rate of weathering is also about 2cm per year the mountains retain their overall altitude. We flew over Fiordland in a 6-seater aircraft; the scenery was magnificent with U-shaped and hanging valleys, cirque lakes, thin threads of waterfalls and folded and contorted sedi-

Figure 5. U-shaped valley, Fiordland. (Please excuse the aeroplane wing - it was holding us up!)

Figure 6. Cirque lake, hanging valley and waterfall, Fiordland.

ments stretching as far as the eye could see (Figures 5 & 6). It is not surprising that the New Zealanders wish to retain this wilderness intact and uncontaminated.

Due to subduction activity there are granite plutons intruded into these Ordovician sediments. One large pluton now houses a hydroelectric power station which features on the tourist route, a partnership made to defray costs. The tour starts with a cruise across Lake Manapouri, the 'head' of water for the power station. As there are no roads all the equipment needed to build and maintain the station had to, and still does, travel by water. We passed several barges towing wooden platforms loaded with timber, concrete, vehicles and other equipment. The next stage is by coach which travels along a road built for the power station between Lake Manapouri and Doubtful Sound, the outlet for the water from the power station. The road was built at great expense through dense rainforest and traverses Wilmot Pass, a high pass between two 1500m mountains; it is 2km long and has a gradient of 1/10. The guide pointed out the change from "temperate" vegetation (beech trees with a dense canopy and clear forest floor) to "tropical" forest vegetation (beech trees with dense canopy, mosses, aphybites, trailing lichens, broadleaved plants and a solidly vegetated forest floor) as we topped the pass; there being far more rainfall on the western side. The power station was hewn out of the solid granite without the use of explosives between 1963-1971. Visitors are taken to the turbine hall which houses 7x100Mw generators; the viewing gallery displays posters detailing the construction and operation of the station. There are no supports in the vast cavern as it is considered that the granite is strong enough to support itself, although there were patches of deformed schists in the walls. Most of the power is sent by overland cable to Comalco Aluminium Smelter at Bluff, some 171km away.

A cruise along Doubtful Sound completes the outward journey. 'Sound' is a misnomer. Named by Captain Cook, who only viewed it from the sea, the Sound is really a glacially-formed fiord with vertical sides. It is very scenic and usually has a myriad of spectacular waterfalls but these were dry due to the drought. This was where we first encountered 'tree avalanches'. Lichens grow on the vertical rock faces and mosses and liverworts grow

Figure 7. Two tree avalanches, Doubtful Sound, Fiordland.

on the lichen; these in turn provide a foothold for shrubs and trees, some of which grow to tens of metres high. As there is no soil all the roots are intertwined; all supported by the 1mm or so that the lichen's hyphae penetrate the rock. Eventually a tree grows too tall or the wind blows too hard and the tree falls, tearing up its intertwined roots and bringing down all the plants growing below on the cliff thus creating the tree avalanche which leaves a large bare vertical rockface scar (Figure 7). This scar is quickly colonised by lichens and the process recycles.

On the return journey we encountered dolphins frisking in the deep water and seals basking in the sun on some wonderfully metamorphosed rocky outcrops. Then back over Wilmot Pass and through the primeval rain forest. We were subsequently interested to see that some of the *Walking with Dinosaurs* TV programmes had used this area as a backdrop.

Another cruise, this time along Milford Sound (another fiord) some 120km northeast of Doubtful Sound. The hand-out for the cruise makes no mention of things geological, but we had an inkling that the Continental Margin Rift was visible at the seaward end of the Sound and, sure enough, just as we rounded the last bend before the open sea, there was a clearly visible line in the forest vegetation, in fact there were two as the Rift splits into the Alpine and Pembroke Faults (Figure 8). The guide confirmed that these lines were the Continental Margin but had never been asked about it before - it beggars belief, it really does!

We returned to Te Anau by air as described above. The pilot was well versed about the Continental Rift and vividly described a "v-shaped gash several miles long in the mountains about 10km to the north", but however much I pleaded he could not fly us over it as his schedule decreed that he fly south, not north. The flight south, however, was wonderfully scenic and only possible due to the unusually fine weather.

Our route then took us along a winding and tortuous road through the mountains to Queenstown in the middle of goldmining country. This is in the extensive metamorphic zone which runs down the eastern side of the Rift then widens out to occupy almost the whole width of South Island in a NW/SE band approximately

Figure 8. The Plate Boundary as exposed in Milford Sound, Fiordland. Top: The Alpine Fault; Bottom: The Pembroke Fault.

120km wide. There are many disused gold mines in this area, some of which have been reopened so that tourists can pan for gold and watch demonstrations of water-blasting and sieving of the alluvium from which the gold is extracted. We did not strike it rich, but flakes and even small nuggets are regularly recovered. Chinese labour was imported to work the mines as there was not

enough New Zealand labour available. The Chinese built their own villages which have been restored; informative and well thought-out noticeboards tell the history of the villages and of the individual characters who lived in them. There is no charge to visitors.

Figure 9. Punakaiki (Pancake Rocks).

Next we headed northeast up the west coast, along the only through road, built on Quaternary sediments sandwiched between the Tasman Sea and the highly metamorphosed Southern Alps mountain range. *En route* we walked to the toes of Fox and Franz Josef Glaciers. Further up the coast we visited Punakaiki (Pancake Rocks). We obviously arrived outside the breeding season as there were no pterosaurs to be seen - unlike on *Walking with Dinosaurs* when the colony was very active! The rocks are flatbedded sandstones of varying degrees of coarseness, the finer layers having weathered faster than the coarse ones leaving pinnacles of rocks which look like piles of pancakes. The sea has excavated many tunnels and there are some spectacular blowholes with the footpaths close enough to catch out the unsuspecting visitor with a sudden drenching.

We continued up the coast until we reached Cape Foulwind, a very apt name for a rocky prominence which houses a large seal colony!

Turning east we noticed on the road map an enigmatic red arrow pointing to a T-junction labelled "Fault Line". On arrival there was a spectacular gorge running north-south, a road running north-south and another to the west over the gorge. After fruitless investigation two miles or so in all three directions we pulled off the road at the junction somewhat confused. This was the only reference we had found to the Plate Margin and we could not find it! However, it slowly dawned on us that on the opposite side of the road to the bridge (to the east) there was a small hill crowned with a v-shaped notch which could be traced to road level. On investigation there was soft sandstone on the north side and granite on the south side whilst the v-shaped gully was full of debris (Figure 10). This unassuming groove was the plate margin! The road had been built over the rift but showed evidence of being frequently repaired!

On to Murchison Town which has been rebuilt after being destroyed by a severe earthquake in 1929. Another earthquake in 1968 dammed the local Mauria River which rerouted itself excavating a channel through the boulder clay. In doing so it uncovered a previously buried fault with a downthrow of approximately 10m. The river still runs over what is now called the Mauria Falls; the waterfall is about 100m wide and very spectacular when in spate.

Figure 10. "Fault Line". Top: The crossroads referred to on the road map, the hill and the gully; Bottom left: granite on the left side of the gully; right: sandstone on the right side of the gully.

We crossed back to Kaikoura on the east coast and took time out to go whalewatching. We were told we should see one whale and be very lucky to see two; in the event we saw six! Also a school of dolphins some 200 strong having a "dolphin of a time".

It was now time to say goodbye to South Island and we boarded the ferry at Picton and sailed along Queen Charlotte Sound and across the Cook Strait to Wellington, a bustling North Island city. The motorway aggression was quite a shock after the peaceful, laid back attitude which pervades South Island.

Having spent a very pleasant and informative morning in the offices of the New Zealand Institute of Geology and Nuclear Sciences we headed north to Wanganui. From there we had intended to take the "scenic route" to Wanganeri National Park but, although the route was certainly scenic, the road was non-existent in places having 'washed out' into the river some 50m below. Due to the 130 sizeable earthquakes per year only arterial roads in New Zealand are tarmaced and 'washouts' are common - but this was worse than most, leaving less than one lane-width to drive on, so we retraced our steps and followed the main coast road to the five-peaked volcano of Egmont, now 150km west of the active rift zone. The map shows five Upper Quaternary andesite peaks surrounded by laharic colluvium. Mount Egmont last erupted in 1755 and is considered 'dormant'. The latest and highest peak at 2518m is still bare rock, but the others have weathered considerably to produce the colluvium and are now covered with scrub. Footpaths have been cut through the scrub and ascend to the summit. However, the soil is very thin and there are many bare patches which show layer upon layer of lava flows.

Figure 11. Mount Egmont, 2518m, last erupted 1755.

The map showed some interesting features to the east of Mount Egmont but to reach them we had to travel north and then turn east onto an unmetalled road. Driving was certainly interesting and very dusty; 1/10 to 1/3 inclines on gravel roads some 100m above rivers with no fencing can be a challenge especially when one meets articulated logging lorries! However it was worth it, for when rounding a corner we came face to face with the three vast volcanoes that comprise the Tongariro National Park which straddles the major fault zone and are the direct result of the subduction zone off the east coast of North Island.

Figure 12. Mount Tongariro, 1967m, last erupted 1926. Blue Lake: top right; two Emerald Lakes: just below middle centre; Red Crater: left foreground.

Again we took to the air in a 6-seater aircraft to view the volcanoes, all three of which are andesitic and active. The oldest, Mount Tongariro, is 1967m high and last erupted in 1926 (figure 12). Hot fume-laden steam belches from fumeroles in a white and yellow gully which is sacred to the Maori and can only be entered with their permission. The summit of Mount Tongariro is multi cratered and has three strikingly beautiful lakes: Blue Lake is 400m wide and 16m deep, the origin of the blue colour has not been established; the two Emerald Lakes are smaller but, despite several attempts, their depth has not been ascertained as every time a rope with a weight is lowered into the liquid the rope dissolves before any measurements can be made! The green colour comes from dissolved sulphur and ammonium chlorite. The Red Crater is the most recent vent and has vertical columnar basalts overlaid by layered basalts, much of which has weathered and formed screes inside the crater.

The second oldest volcano has the classic conical shape depicted in all textbooks. Mount Ngauruhoe is frequently erupting and lava flows, now in various shades of red, green, grey and white, have overtopped the crater and spilled down the flanks of the volcano (Figure 13). There are two craters on the summit, a newer one inside a previous one. The latest crater has a central plug with steam issuing from round the edges. We just hoped the plug would hold for the next ten minutes or so while we took our aerial photographs!

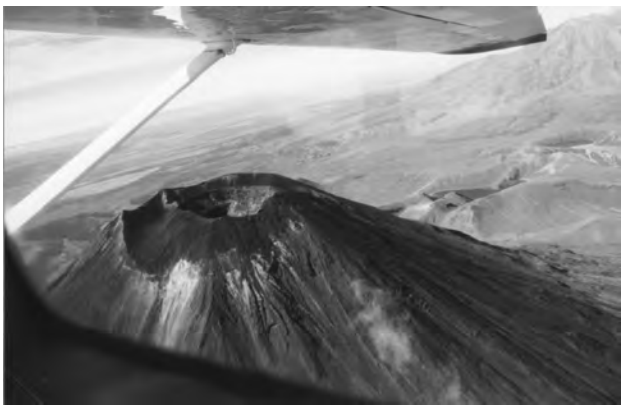

Figure 13. Mount Ngauruhoe, constantly erupting.

Figure 14. Mount Ruapehu, 2797m, recent sizeable eruptions 1945, 1969, 1975, and 1995-6. Bubbling crater lake in the foreground; glaciers in the background.

Mount Ruapehu is the biggest and newest volcano in this cluster. It has seriously erupted in 1945, 1969, 1975, and 1995-6 but on Christmas Eve in 1953 a small eruption melted one of the summit glaciers causing a lahar which swept down the valley collecting all in its path. There happened to be a train crossing a river bridge at the time - a monument to the Wellington to Auckland Express KA 949 and its 151 passengers marks the spot. The two outer remnants of the glacier still cover the flank near the summit.

The latest explosive eruptions blew away the top of the volcano which stands today at 2797m. There are several overlapping craters most of which support glaciers, but the newest contains a steaming and bubbling crater lake at a temperature of 20-40°C, the bubbling due to gas emitted from below (Figure 14). The pilot said the fumes were highly toxic and that several people had died as a result of inhalation. The glaciers were only several metres above the surface of the lake and it did not take much imagination to see that it would not take much uplift to repeat the event of 1953; the pilot agreed.

On the way back to the airfield we flew over the campsite at 1130m on the mountain flank where we had spent the night and noticed that it was in the direct line of a valley reaching to the summit of Mount Ruapehu! A large hotel and several holiday and

skiing complexes were also built in the same valley - the New Zealanders are so used to their earth moving that they take no notice until it happens.

As we drove north towards Rotorua the ground began to steam and 'that smell' of hot sulphur pervaded the air. In Rotorua itself steam issued from every stream, grate, manhole cover, cracks in the gardens, cracks in the road, in fact everywhere. There are several tourist parks with names such as Wai-O-Tapu (Sacred Water) and Craters of the Moon which "opened up overnight" in 1983. They feature steaming rifts and streams, sulphur-belching fumeroles, bubbling mudpools, multicoloured lakes and yellow sulphur-lined craters with bleached lifeless surrounds. There are no fences, just a request to keep to the paths, but we noticed several visitors who were lucky not to suffer as a result of their desire to get sensational photographs!

Figure 15. Champagne Pool, Wai-O-Tapu, Rotorua.

There was very little information and what there was could sometimes be confusing. Some of the lakes were lethal; the Champagne Pool (Figure 15) had a notice which said:

"Occupies a sinter lined 900 year old explosion crater. The pool's surface covers 4000m^2. The gas bubbles rising to the surface are harmless carbon dioxide giving the 'bubbly' effect. The alkali chloride water contains gold, silver, antimony, arsenic, thallium and mercury as well as a host of other minerals. The water temperature is 74-76°C with a pH of 5.4."

We kept to the paths.

Although we saw several flightless birds in the wild, Kiwis are rare and can only be viewed in a couple of 'dark houses' where no cameras are allowed. One such place just outside Rotorua is called Rainbow Springs where all the natural environments of New Zealand have been recreated and where they successfully keep samples of all the species of plants and animals. They also have a pair of tuataras - lizards which are reputed to live as long as 300 years and have remained unchanged for 225Ma (Figure 16).

Leaving the sulphurous smells behind we travelled northwest through Auckland to the Bay of Islands, a very pretty and scenic area. A cruise in a catamaran passes tree-covered granitic islands,

Figure 16. A pair of tuataras, reputed to live to be 300 years old. These lizards have remained unchanged for 225Ma.

seastacks of folded Permian greywackes and an intriguing collection of stacks called 'The Black Rocks' which were columnar basalts, mostly upright but some bent and contorted into vertical sheets (Figure 17). They were very striking; the seawater having

Figure 17. "Black Rocks", columnar basalts, Bay of Islands.

weathered the tidal zone grey, while the upper columns remained black. A trip in a glass-bottomed boat over a coral reef completed the tour of the various ecosystems.

Sadly our time in New Zealand was now exhausted. We had followed the Continental Rift from its southern outcrop at Milford Sound, through South and North Islands to Rotorua and the Bay of Plenty, viewing it and the results of its activities wherever possible. We had driven 6000 miles in 6 weeks, 4 weeks on South Island and 2 weeks on North Island. During that time there were at least 15 earthquakes - and we had not noticed any of them!

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Authors

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Branch Reports

East Anglia

This year we began with a Day of Talks and AGM attended by over 30 people. Richard Pusey began by telling us about the OUGS trip to the Oman; it was Richard's first geological talk and was excellent. After coffee Dr Jan Alexander from UEA talked about the Holocene delta development in Queensland. Little research had been done due to 100% humidity, mosquitoes, snakes and deadly spiders. The slides looked wonderful; when it's dry, the streams are trickles but when it's wet 54cm of rain can fall in 24 hours. After lunch Dee Edwards talked about the trip to Germany entitled *Annihilating Archaeopteryx with Asteroids*. The AGM followed.

We had two other evening talks this year: Dr Monica Grady from the Natural History Museum talked about meteorites, mainly from Mars, and brought several specimens for us to look at. She explained how they decided they were from Mars as they did not say "Mars" on them! Dr Julian Andrews came to Norwich in September to talk about the Holocene Environment in the Humber and a project to study organic carbon, nutrients and trace metals in saltmarsh and estuarine sediments.

Three day field trips were organised. Tim Wright from Brighton University led a visit to the new tunnel being dug by Anglian Water at Ipswich. The visit was so popular that the trip had to be run twice, an all-time record for East Anglia. The side tunnel we had hoped to walk along had been finished early and was closed but it was still interesting to find out what is below Ipswich. Alan Dawn led two trips, one in May to Ketton Quarry and one in October to Peterborough Museum and the Kings Dyke Brick Pit. Alan showed us the plesiosaur which he has had named after him but we did not find any whole specimens ourselves, although a few bones were found.

In June Dr Gareth George led our Weekend trip to Crickhowell where the scenery was beautiful as we walked along valleys to waterfalls. Sandstones, shales, Millstone grit and limestones were a welcome change from East Anglian rocks. On the Sunday we went to Big Pit Blaenafon and then to Ross on Wye to look at the cross bedding by the roadside.

The winter weekend was certainly different. Due to a double booking, Dave Green was unable to lead the trip on the Saturday so, armed with a list of grid references and the briefest description of the site, the trip went ahead. Dave was there in the evening to answer any questions. Church Stretton has no resemblance to East Anglia at all! The weather was good and everyone came away with knowledge of the Cambrian - Silurian as well as several fossil and mineral specimens.

Wendy Hamilton

East Midlands

This end of Millennium report starts off with Snowflake 98 to the Vale of Eden, where the sunshine glinting on the heavy frost told just how cold it was; unfortunately the hotel was a little bit on the chilly side. January: AGM (in brewery); February: Branch Dinner; March: Basic Geology; Easter: Isle of Wight; May: National Coal Mining Museum; June: wet on The Roaches; July: three people for a Quaternary visit.

August: Eclipse Year (the end of the world) saw the largest field trip under canvas. Ninety seven people in Cornwall were lucky enough to actually see the totality. September: Revision Trip and Revision Workshop; October: last ever visit to a Leicestershire Quarry (due to safety regulations). Over the year we had three lectures. Attendance: (apart from the July trip) well done; lectures: could have been more at each of them.

So what about this attendance thing? It has been our premise that field trips are the core of the provision that the branch should make for its members; a variety, a diversity of sites, leaders and approach that should satisfy the geologists who join the Society. Then why are a relatively small proportion of the membership partaking in trips? A survey was conducted in 1998 and the conclusion was that there were no magic answers, no magic solutions that would make people want to attend events; we had adopted some of the suggestions with, as yet, no obvious result. We have publicised the trips in the newsletters, we have tried e-mailing those with notice just before a trip to remind them with the result that we now get apologies for absence on trips!

But there has been a change - the hard core has changed. The people regularly coming on events ten years ago are largely not the same as those regularly coming onto events today - in some cases *anno domini*, in some cases changes in interest. Yet we still have a hard core; those loyal people who try to involve themselves as Branch Members who we hope get as much out of their membership as they feel they can. So we will just have to content ourselves that we see on a regular basis so few of the branch, but are able to keep in communication with the members who are not able to attend through Chippings (now ten years old), and accept their tacit support. Without you we would not have a branch. Thanks to everyone.

John Colby

East Scotland

Attendance at the AGM in January was similar to last year with 11 people braving the winter weather. Again the Branch Organiser had expressed a desire to stand down but no-one else was prepared to stand, so I agreed reluctantly to continue for another year. The Treasurer reported that the Branch accounts were in a healthy position.

In March the first field trip of the year was a rather drier version of last autumn's Arbroath cliffs washout, led by Jenny Allen. It was an exploration of the Old Red Sandstone from the clifftops and, later, from the beach. We then explored it "from the inside", with a torchlight trek through a large cave emerging in the next bay along (where we found green jasper); we returned via a smaller cave. After lunch the beach at Lunan Bay provided an opportunity to search (unsuccessfully) for agates.

In May we had a trip to the East Neuk of Fife with Bede Pounder exploring the Carboniferous sediments and volcanics along the shore between Elie and St Monans. A hunt for "Elie Rubies" (a type of garnet called pyrope) was unsuccessful, but Bede's leadership ensured that everyone had an enjoyable time.

A combined geological/botanical/ornithological field trip to St Cyrus National Nature Reserve followed in June led by Brian Allen. A long raised beach with dunes and extensive saltmarsh provided the habitat for many interesting plants, including the Clustered Bellflower and the Nottingham Catchfly, both of which are very rare in Scotland. Behind the raised beach, some 700m inland, lies a line of tall lava cliffs which in places look so fresh that you half expect the tide to come in. A colony of fulmars has made these cliffs their home, although some doubt was expressed over how many of the young actually make it successfully to the sea.

In July the National Symposium came to Aberdeen. Several of our members helped in the organisation and what a superb weekend it was! Excellent talks, field trips and social life, complete with typical Aberdeenshire sunny weather (well sometimes).

The Branch Organiser's "local patch", Gosford Bay in East Lothian, was the scene of the August field trip. Carboniferous sediments flank most of the bay, with a good selection of trace fossils both on and in ripple-bedded sandstones. There were also crinoidal limestones and a colonial coral bed known colloquially as "spaghetti rock" because of its resemblance to that kind of pasta! A variety of dolerite intrusions were examined as well as a "crypto-vent", a more or less circular patch of broken and jumbled sandstones showing where an upward drilling of magma had been arrested shortly before it broke the surface.

The long weekend trip in September was to Aberdeenshire, led by Dr Graham Smith. We were based in Oldmeldrum and, unlike every other trip so far this year, we did not visit the coast once! We did see a wide variety of intrusive rocks, ranging from ultrabasic to acid, in a series of both active and inactive quarries and other exposures. The interrelationships between the various intrusions at least partly enabled us to establish their relative ages. The presence or absence of contact metamorphism in the Dalradian country rocks was also studied. On a rather wet